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THE RELATION OF OIL SHALE TO PETROLEUM

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ABSTRACT

It is believed by a number of geologists that oil shale is genetically related to petroleum and that it represents the initial stage in the transformation of organic material into oil. These investigators have assumed that at elevated temperatures and pressures, induced by deep burial, the "kerogen" of oil shales would be converted into petroleum which might accumulate under favorable structural conditions to form pools of oil.

In order to test this hypothesis the writers undertook a series of flowage experiments on typical oil shale both at ordinary temperatures and at elevated temperatures. In view of the results obtained there is reason for doubting that important quantities of petroleum have been formed from oil shales except in the vicinity of igneous intrusions where the temperatures have been unusually high. It is suggested that the initial stages of transformation of organic débris have been different in the formation of "kerogen" than in the formation of oil.

INTRODUCTION

Before entering upon a discussion of the relation of oil shale to petroleum a definition of oil shale in the light of recent investigations is in order. A common conception among those not thoroughly familiar with the subject is that oil shale contains free oil as such. In reality true oil shale contains little or no free oil, but rather complex organic constituents which are capable of being converted into oil at elevated temperatures. These are chiefly amorphous in character and are usually called "kerogen."

From nearly all oil shale 1 to 3 per cent of bitumen is easily extractable with chloroform at ordinary temperatures, and it is

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usually assumed that this is present in the shale as free oil. However, the writers are of the opinion that this is derived from a more easily soluble part of the "kerogen."

"Kerogen" has previously been regarded as insoluble in organic solvents, but recent investigations by the junior author have shown that the "kerogen" of all oil shales examined in this study is slowly soluble in chloroform, and that the amount of oil extracted varies directly with the time of treatment. For example, samples of representative oil shales from Dragon, Utah, Elko, Nevada, De Beque,

TABLE I

Analysis of De Beque, Colorado, Oil Shale

	Percentage
Water driven off by heating sample at 100° C. for six hours	1.51
Additional water formed by the decomposition of hydrated constituents in the shale prior to oil eduction	.15
Oil extracted with chloroform during three hours at ordinary temperatures (minus 120-mesh shale)	2.09*
Oil formed by the thermal decomposition of "kerogen"	19.59
Gases evolved during oil eduction	10.44†
Gases evolved above the temperature of oil eduction, including gases formed by oxidation of fixed carbon	19.00
Nitrogen	.72
Mineral ash residue	46.50
Total	100.00

* Bitumen contains 2.31 per cent nitrogen.

† Percentage includes a small amount of additional water of dehydration.

Colorado, and Ashland, Ohio, upon being exposed to the solvent action of chloroform in a modified Soxhlet apparatus at successive intervals of variable time, gave the results indicated in Figure 5. It will be observed that the early part of each curve rises steeply. This is probably to be accounted for on the basis of the presence of a small, though variable, percentage of easily soluble "kerogen" in each specimen. In the case of a sample from the property of the Ventura Refining Company, near the source of Boush Creek, about fifteen miles from the town of De Beque, Colorado, nearly one-half of the "kerogen" was extracted over a period of 309 hours. The shale was ground to pass a 120-mesh screen. An analysis of this shale is given in Table I.

In a number of instances the De Beque sample was exposed to a

temperature of 100° C. in the drying oven for several hours before being treated with chloroform. However, the effect of temperature upon the solubility of "kerogen" appears to be inappreciable, as indicated by the results.

After the eighth extraction, petroleum ether was used as a solvent in place of chloroform, but with entirely negative results. The tests were then continued with the chloroform solvent. No perceptible difference was noted in the character of the bituminous residue obtained from the first chloroform extraction when compared to those secured in the succeeding determinations. Nevertheless, the bituminous material came off much more rapidly early in the first extraction than at any later time, as indicated by rapid discoloration of the chloroform.

It is not the intention of the authors to digress on the subject of the origin of "kerogen" in this paper, but we take this opportunity to register our disagreement with E. H. Cunningham-Craig who has recently expressed himself to the effect that "the 'kerogen' of oil shale is the colloidal combination of the fine absorbent matter of the shale with an inspissated petroleum which may have migrated for a great distance before reaching its present position."[1] There is not the slightest evidence of any diffusion of free oil through the Rocky Mountain oil shales. Furthermore, the "kerogen" of these shales has entirely different chemical properties than the residues of inspissated petroleum. The uniformity of the "kerogen" content of individual shale layers over large areas and the regular interbedded relationship of rich, lean, and barren layers of shale is likewise difficult to explain on the basis of this theory.

For the sake of argument let us assume that Cunningham-Craig is correct in his theory that "kerogen" represents inspissated petroleum which has migrated into the shales. Now in case of the rich oil shales of the Rocky Mountain region the "kerogen" content frequently amounts to more than 25 per cent by weight, and more than twice this amount by volume. The average porosity of ordinary shale is considerably less than 5 per cent. How, then, can petroleum residues accumulate to the extent of 50 per cent by volume without disturbing or deforming the strata in the slightest manner?

[1] *Bull. Amer. Assoc. Pet. Geol.*, Vol. 9 (1925), p. 180.

It has been assumed by several geologists that oil shales are genetically related to petroleum, and that their "kerogen" content represents an incipient stage in the transformation of organic material into oil. These investigators have assumed that at elevated temperatures and pressures induced by deep burial or by deformation the "kerogen" would be converted into petroleum, which might accumulate under favorable structural conditions to form pools of oil.

In order to test this hypothesis the writers undertook a series of experiments on typical oil shales, first at elevated pressures and ordinary temperature, and then at both elevated temperatures and pressures. The results of the high-pressure experiments at ordinary temperatures have already been published.[1] In these, cylinders of oil shale were caused to flow in specially constructed steel spools (Figs. 1, 2, and 3). Quantitative determinations of the free oil content of the shale before and after flowage indicated that no free oil was produced at elevated pressures.

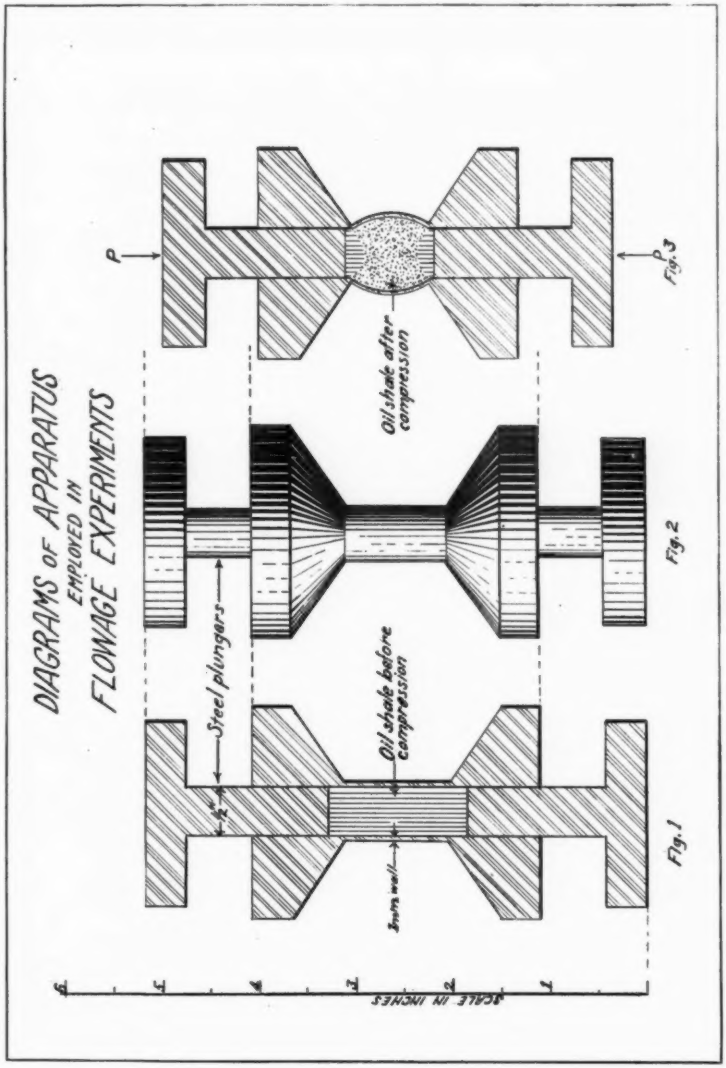
In order to determine the effect of elevated temperatures together with elevated pressures, similar flowage experiments were made with the apparatus partly immersed in a metal bath contained in a flat-bottomed steel vessel designed for the purpose (Fig. 4).

APPARATUS FOR FLOWAGE EXPERIMENTS AT ELEVATED TEMPERATURES

Spool-like cylinders fitted with steel plungers and of the same dimensions as those employed in the experiments previously described were prepared. Cylinders of oil shale were turned down on the lathe, parallel to the stratification, until a diameter of one-half inch was obtained. These were next cut into lengths of 1.6 inches, the end cuttings being saved and used in the preliminary analyses. A flat-bottomed steel vessel prepared by welding a machined steel disc to a steel cylinder 3.15 inches in diameter and 4.5 inches high was used as a container for metal baths in which the spools were partly immersed during the experiments.

For the lower-temperature experiments a bath of mercury was employed, and for the higher temperature test, molten solder. Heat

[1] Van Tuyl and Blackburn, *Bull. Am. Assoc. Pet. Geol.*, Vol. 9 (1925), p. 158.


DIAGRAMS OF APPARATUS
EMPLOYED IN
FLOWAGE EXPERIMENTS
Steel plungers
Oil shale before compression
Oil shale after compression
Iron wall
P
P
SCALE IN INCHES
6
5
4
3
2
1
Fig. 1
Fig. 2
Fig. 3

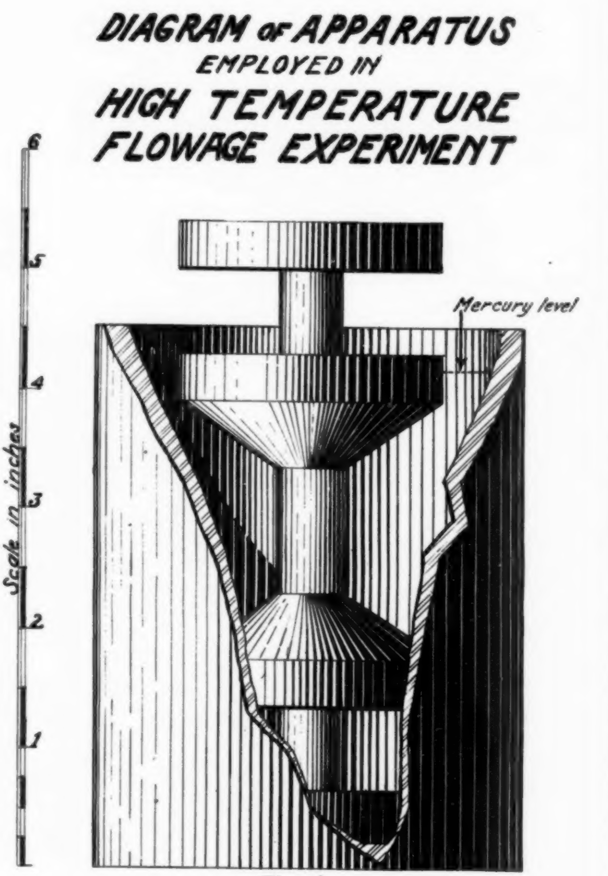


DIAGRAM OF APPARATUS
EMPLOYED IN
HIGH TEMPERATURE
FLOWAGE EXPERIMENT
Mercury level
Scale in inches
6
5
4
3
2
1

Fig. 4

was applied by directing the flame of a gasoline blowtorch against the outer wall of the metal container, the temperature being regulated by means of a thermometer inserted in the bath between the steel spool and the container. A preliminary observation at elevated temperature having shown that the temperature of pulverized shale within the steel spool after a few seconds' immersion was almost identically the same as that of the bath outside, it was assumed that the temperature of the shale cylinders was essentially the same as that of the metal bath during the high-pressure experiments.

It was the original intention of the writers to conduct the flowage experiments at temperatures which would normally decompose the "kerogen" into oil under atmospheric pressure, and to observe whether the effect of the flowage pressure would decrease the amount of soluble oil formed. However, after preliminary tests, it was considered inadvisable to perform flowage experiments at such a high temperature owing to the probability of the generation of sufficient gases in the steel spool to burst the wall before the pressure at which rock flowage is pronounced could be reached. Three high-pressure flowage experiments, therefore, were made at a temperature of 100° C., and one at 220° C. Analyses of the readily soluble bitumen content of the shales employed were made both before and after the experiments and the results compared.

DESCRIPTION OF FLOWAGE EXPERIMENTS AT ELEVATED TEMPERATURES

Experiment 1.—This experiment was conducted with the steel spool partly immersed in a mercury bath held at 100° C. Assuming a normal increase in temperature of 1° C. for each 100 feet of added depth, and a mean annual temperature of 10° C. at the surface, this temperature would be equivalent to that at a depth of 9,000 feet in the earth's crust.

A cylinder of the Grand Valley, Colorado, oil shale was placed in the spool and the steel plungers inserted at the ends. These were adjusted so that the shale cylinder occupied a central position. The apparatus was then placed in the steel vessel into which mercury was poured to a level of about three millimeters below the top of the steel spool. The vessel was next transferred to a Riehle testing

machine and the pressure raised to 1,000 pounds, equivalent to 5,102 pounds per square inch, the temperature of the mercury being elevated simultaneously from 21° C. to 100° C. by means of a gasoline blowtorch. By careful adjustment the temperature was prevented from fluctuating more than two degrees from this temperature during the remainder of the experiment. After standing under this load for five minutes, the pressure was raised by the steps shown in Table II. It was not possible to indicate definitely the time and pressure at which flowage actually began, owing to the fact that the

TABLE II

ROCK FLOWAGE EXPERIMENT ON GRAND VALLEY, COLORADO, OIL SHALE AT TEMPERATURE OF 100° C.

Total Load on Cylinder as Recorded by Pressure Machine	Unit Pressure on Cylinder of Oil Shale* (Pounds per Square Inch)	Time in Minutes at Various Pressures	Total Time Specimen Was Subjected to Pressure		Remarks
			Hours	Minutes	
1,000	5,102	5	......	05	....
2,000	10,204	10	......	15	....
3,000	15,306	5	......	20	....
4,000	20,408	5	......	25	....
4,500	22,959	5	......	30	Incipient flowage
5,000	25,510	10	......	40	More rapid flowage
5,500	28,061	10	......	50	More rapid flowage
6,000	30,612	10	1	00	Flowage very rapid
6,500	33,163	20	1	20	Spool burst, releasing steam

* Diameter of shale cylinder, .5 inch; area of head of shale cylinder, .196 square inch; pressure on shale cylinder, 5.102 times recorded pressure.

spool was not open to view. However, when a pressure of 4,500 pounds, equivalent to 22,959 pounds per square inch, was reached difficulty was experienced in maintaining this pressure. Under greater loads the falling off was still more noticeable, and at 6,500 pounds, equivalent to 33,163 pounds per square inch, the spool burst, releasing sufficient steam to cause several bubbles in the mercury. The steel spool was then lifted from the mercury bath and the flowed shale removed. There was a slight contamination of the shale with small globules of mercury, but it was comparatively easy to separate these mechanically. The shale, upon being examined under the microscope, showed no traces of free oil.

After pulverizing the sample to pass an 80-mesh screen, a carefully weighed portion was extracted with chloroform at ordinary temperatures, using a modified Soxhlet extraction apparatus. The amount of easily soluble bitumen was found to be 1.30 per cent, as compared to 1.23 per cent before pressure. This is within the limit of experimental error, considering the ease with which the more soluble "kerogen" is extracted during the first few hours of exposure to the solvent.

Experiment 2.—In this experiment an attempt was made to determine the effect of rock flowage upon the same Grand Valley oil shale as employed in the preceding experiment, at a temperature above 100° C., but below the initial decomposition temperature of the "kerogen." Earlier experimental work having indicated that the initial temperature of decomposition into oil was between 315° C. and 340° C., a temperature of 220° C. was decided upon. Solder with a melting point of 215° C. was used as a bath. After having melted a sufficient amount of solder in the container, a steel spool containing a cylinder of the oil shale was placed in the bath and the apparatus properly adjusted in the pressure machine. Unfortunately, however, the spool burst as a result of accumulated steam and hydrocarbon gases before the pressure could be raised to the point of rock flowage. Nevertheless, it was deemed advisable to determine if any free oil was formed in the shale as the result of this treatment. The easily soluble bitumen obtained amounted to .77 per cent, as compared to 1.23 per cent in the original sample. The difference is believed to be accounted for by conversion of part of the easily soluble bitumen to gas, which escaped when the spool burst.

Experiment 3.—Using the same apparatus as in the preceding experiments, a sample of oil shale from De Beque, Colorado, was subjected to pressure in a bath of mercury held at a temperature of 100° C. An analysis of this shale before compression is given in Table III.

Flowage apparently began at a pressure of about 20,408 pounds per square inch, as suggested by the fact that it was difficult to retain the pressures reached on the compression machine at this and succeeding higher loads. After a load of 23,979 pounds per square inch was held for ten minutes by frequent adjustment of the

machine, the pressure fell off rapidly to 15,306 pounds per square inch as a result of the bursting of the steel spool.

After removing the shale from the spool and separating numerous small, contaminating globules of mercury, the shale was crushed to

TABLE III

ANALYSIS OF DE BEQUE, COLORADO, OIL SHALE

	Percentage
Water extracted with chloroform	0.34
Water driven off by heating three and one-half hours at 100° C.	0.24
Easily soluble bitumen extracted with chloroform during two hours	1.96
Remaining volatile constituents	54.61
Mineral ash	42.85
Total	100.00

pass an 80-mesh screen and the easily soluble bitumen extracted with chloroform. The easily soluble bitumen content of the flowed shale amounted to 1.99 per cent, while a sample of the untreated shale was found to contain 1.96.

TABLE IV

ROCK-FLOWAGE EXPERIMENT ON DE BEQUE, COLORADO, OIL SHALE AT TEMPERATURE OF 100° C.

Total Load on Cylinder as Recorded by Pressure Machine	Unit Pressure on Cylinder of Oil Shale* (Pounds per Square Inch)	Time in Minutes at Various Pressures	Total Time Specimen Was Subjected to Pressure		Remarks
			Hours	Minutes	
1,000	5,102	20	......	20	....
1,500	7,653	15	......	35	....
2,000	10,204	15	......	50	....
2,500	12,755	15	1	05	....
3,000	15,306	15	1	20	....
3,500	17,857	15	1	35	....
4,000	20,408	15	1	50	Incipient flowage
4,450	22,704	15	2	05	More rapid flowage
4,700	23,979	15	2	20	Spool burst

* Diameter of shale cylinder, .5 inch; area of head of shale cylinder, .196 square inch; pressure on shale cylinder, 5.102 times recorded pressure.

Experiment 4.—With the object of determining if the eastern oil shales would give the same results as typical specimens from the Rocky Mountain region, a sample of Devonian oil shale from Ashland, Ohio, capable of yielding 21 gallons per ton by the usual assay method for oil determination, was subjected to flowage at a

temperature of 100° C. The experiment was carried on under the same conditions as experiments 1 and 3, except that the specimen was subjected to elevated temperature and pressure over a longer period of time (4 hours and 17 minutes). In order to prolong the

TABLE V

FLOWAGE EXPERIMENT ON ASHLAND, OHIO, OIL SHALE AT TEMPERATURE OF 100° C.

Total Load in Pounds on Cylinder of Oil Shale as Recorded by Pressure Machine	Unit Pressure on Cylinder* of Oil Shale (Pounds per Square Inch)	Time in Minutes at Various Pressures	Total Time Specimen Was Subjected to Pressure		Remarks
			Hours	Minutes	
1,000	5,102	15	......	15	....
1,500	7,653	10	......	25	....
2,000	10,204	20	......	45	....
2,500	12,755	15	1	00	....
3,000	15,306	15	1	15	....
3,250	16,581	15	1	30	....
3,500	17,857	10	1	40	....
3,750	19,132	15	1	55	....
4,000	20,408	15	2	10	....
4,250	21,683	10	2	20	....
4,500	22,959	10	2	30	....
4,750	24,234	10	2	40	....
5,000	25,510	10	2	50	....
5,250	26,785	10	3	00	Incipient flowage
5,300	27,041	15	3	15	Incipient flowage
5,400	27,551	5	3	20	Incipient flowage
5,500	28,061	5	3	25	Incipient flowage
5,600	28,571	5	3	30	Distinct flowage
5,500	28,061	2	3	32	Flowage continued
5,400	27,551	2	3	34	Flowage ceased
5,450	27,806	11	3	45	Flowage ceased
5,500	28,061	5	3	50	Slow flowage
5,550	28,316	10	4	00	Slow flowage
5,600	28,571	5	4	05	Slow flowage
5,700	29,081	10	4	15	Rapid flowage
5,800	29,592	2	4	17	Very rapid flowage

* Diameter of shale cylinder, .5 inch; area of shale cylinder, .196 inch; pressure on shale cylinder 5.102 times recorded pressure.

period of rock flowage, the pressure was allowed to fall off slightly for a short time after distinct flowage began. It was then stepped up slowly to a load of 5,800 pounds, equivalent to 29,592 pounds per square inch, when flowage became very rapid (see Table V). After standing at this pressure for two minutes, the apparatus was removed from the machine. The middle portion of the steel spool was

found to be strongly bulged, but it had not burst, as in the preceding experiment.

A careful determination of the easily soluble bitumen content of the original untreated shale indicated it to be 1.64 per cent, while the average of two determinations of the easily soluble bitumen of the flowed shale was 1.67 per cent.

In order to determine if the flowage of the shale had affected the properties of the more difficultly soluble "kerogen" of the oil shale, several extractions were made over the same periods of time of both the original untreated shale and the flowed shale. Strangely enough, the solubility of the "kerogen" of the flowed shale was found to be consistently less than that of the original shale. This relationship is expressed by means of curves in Fig. 5. It will be observed that the curves practically coincide in position for about the first ten hours of extraction, and then diverge. The extraction of "kerogen" was not carried to completion in either case. It would be interesting to determine if the solubility curves of the "kerogen" of other oil shales, before and after flowage, show a similar relationship.

THE EFFECT OF FLOWAGE ON THE DECOMPOSITION TEMPERATURE OF "KEROGEN"

The influence of the rock flowage on the constitution of the "kerogen" of the Ashland, Ohio, oil shale was further tested by a heat treatment of the original shale and of the flowed shale, and a comparison of the results obtained. A sample of the original shale, upon being placed in a pyrex glass test-tube, was heated in a bath of molten tin for a period of one hour and seven minutes, the temperature of the bath being raised by five-degree steps from 340° C. to 365° C. The temperature of the shale within the glass tube was checked with that of the bath and was found to be considerably less, ranging from 305° C. to 340° C. (see Table VI).

In the early stages of heat treatment a considerable amount of moisture was given off from the shale, and when the temperature of the shale reached 321° C. minute globules of yellowish oil appeared on the wall of the tube. The amount of oil slowly increased until the tube was removed from the bath. The free oil and the shale were then washed from the tube by means of chloroform and the

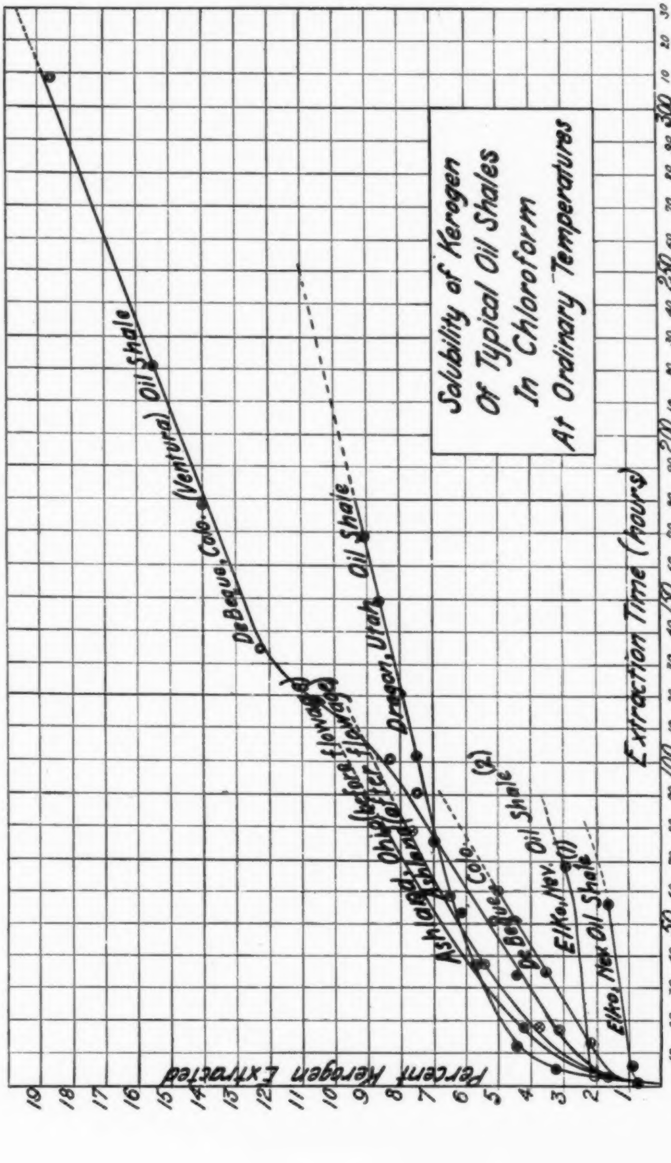

Solubility of Kerogen
Of Typical Oil Shales
In Chloroform
At Ordinary Temperatures
Extraction Time (hours)
Percent Kerogen Extracted
DeBeque, Colo. (Ventura) Oil Shale
Dragon, Utah Oil Shale
Ohio (before flowage)
(after flowage)
Ashland
DeBeque, Colo. (2)
Elko, Nev. Oil Shale (1)
Elko, Nev. Oil Shale

FIG. 5

shales separated by filtration. The shale and chloroform-oil solution were then transferred to a modified Soxhlet extraction apparatus and treated for one hour and thirty-five minutes. The amount of soluble bitumen obtained was 2.87 per cent.

TABLE VI

HEAT TREATMENT OF ASHLAND, OHIO, OIL SHALE BEFORE FLOWAGE

Temperature of Tin Bath (Degrees Centigrade)	Temperature of Shale in Tube (Degrees Centigrade)	Time in Minutes at Various Temperatures	Total Time in Minutes of Heat Treatment	Remarks
340........	305	17	17	Moisture condensed on wall of tube
345........	314	10	27	
350........	321	10	37	Minute globules of brownish-yellow oil condensed on walls of tube immediately above the shale
355........	328	10	47	
360........	336	10	57	
365........	340	10	67	

The foregoing operation was then repeated, using a sample of the same shale which had been subjected to flowage. The temperature of the bath was raised at the same intervals of time, and with the same increments, as in the above test. In the early stage of this experiment the temperature of the shale within the tube was a number of degrees higher than in the preceding operation, but the variation became gradually less in the final stages (see Table VII).

TABLE VII

HEAT TREATMENT OF ASHLAND, OHIO, OIL SHALE AFTER FLOWAGE

Temperature of Tin Bath (Degrees Centigrade)	Temperature of Shale in Tube (Degrees Centigrade)	Time in Minutes at Various Temperatures	Total Time in Minutes of Heat Treatment	Remarks
340........	317	17	17	Moisture condensed on wall of tube
345........	321	10	27	
350........	325	10	37	Minute globules of brownish-yellow oil condensed on wall of tube immediately above the shale
355........	329	10	47	
360........	334.5	10	57	
365........	341	10	67	

The variation may possibly be accounted for by the smaller content of moisture in the flowed shale. It will be recalled that this was subjected to a temperature of 100° C. during the flowage experiment. The shale and soluble oil were removed from the tube and treated

with chloroform in the Soxhlet apparatus for one hour and thirty-five minutes as in the above case. The amount of easily soluble bitumen in the flowed shale after heat treatment was found to be 2.07 per cent, as compared to 2.87 per cent obtained from the unflowed shale. It appears that the effect of flowage was to render the

TABLE VIII

HEAT TREATMENT OF GRAND VALLEY, COLORADO, OIL SHALE BEFORE FLOWAGE

Temperature of Tin Bath (Degrees Centigrade)	Temperature of Shale in Tube (Degrees Centigrade)	Time in Minutes at Various Temperatures	Total Time in Minutes of Heat Treatment	Remarks
340........	316	17	17	
345........	323	10	27	Minute globules of yellowish oil condensed on wall of tube immediately above the shale
350........	329	10	37	
355........	334	10	47	
360........	340	10	57	
365........	344	10	67	

TABLE IX

HEAT TREATMENT OF GRAND VALLEY, COLORADO, OIL SHALE AFTER FLOWAGE

Temperature of Tin Bath (Degrees Centigrade)	Temperature of Shale in Tube (Degrees Centigrade)	Time in Minutes at Various Temperatures	Total Time in Minutes of Heat Treatment	Remarks
340........	316	17	17	
345........	323	10	27	Minute globules of yellowish oil condensed on wall of tube immediately above the shale
350........	329	10	37	
355........	335	10	47	
360........	340	10	57	
365........	344	10	67	

"kerogen" less susceptible to thermal decomposition, as well as to render it less soluble.

In order to determine if the effect of rock flowage upon the thermal decomposition of a typical Rocky Mountain oil shale would be the same, a sample of Grand Valley, Colorado, shale which had been subjected to flowage at ordinary temperatures[1] was subjected to the identical heat treatment as outlined above. The temperatures of the shales within the pyrex tube checked very closely in each test (see Tables VIII and IX).

[1] See preliminary paper by the authors, *Bull. Amer. Assoc. Pet. Geol.*, Vol. 9 (1925), pp. 161–63.

The amount of easily soluble bitumen in the flowed and unflowed shale before the heat treatment averaged 1.95 per cent. The amount of easily soluble bitumen in the unflowed shale after the heat treatment was found to be 1.99 per cent, and in the flowed shale after heat treatment, 2.01 per cent. It is probable that a small amount of gas was given off from both this shale and the Ashland, Ohio, shale during the heat treatment. However, this was at no time sufficiently concentrated to ignite when a flame was held at the mouth of the test tube. Apparently the flowage of the Grand Valley, Colorado, shale had no important effect on the decomposition temperature.

CONCLUSIONS

Inasmuch as it has not been possible to produce free oil from the kerogen of typical oil shales or to lower their initial decomposition temperature by causing them to flow both at ordinary temperatures and at elevated temperatures equivalent to those which would normally exist at a depth of more than 8,000 feet in the earth's crust, the authors are of the opinion that important quantities of petroleum have not been formed from oil shales in nature, except possibly in the vicinity of igneous intrusions where the temperatures have been unusually high. In fact, it is suggested that oil shales have remained oil shales to the present day for this very reason. If it were possible for "kerogen" to change to petroleum, why should important deposits of oil shales which have been deeply buried be preserved at the present time? In the case of certain of the Nevada and Scotch oil shales, the deposits have been subjected to folding and faulting and they are considerably deformed. Yet they contain a large amount of "kerogen" which has not been converted to petroleum, and so far as we are aware, neither important quantities of free oil or oil residues are present in the oil shales themselves or in the associated formations.

We are, therefore, of the opinion that "kerogen" and petroleum are not genetically related, but represent different end products of the transformation of organic débris. Possibly differences in bacterial action at the time of deposition, or some other causes, are important in determining the character of the final product obtained.

SOME EXPERIMENTAL WORK TESTING THE HYDRAULIC THEORY OF OIL MIGRATION AND ACCUMULATION BY MEANS OF THE DOWNWARD CIRCULATION OF WATER

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ABSTRACT

This paper presents the results of some experimental work, testing the hydraulic theory of oil migration and accumulation, carried on in a plate-glass box in which a sand seam, bounded on both top and bottom by a layer of clay, was arranged to give the effect of a dome on the rim of an artesian basin. Crude oil introduced at the intake of the sand was carried through the sand by slow, downward-moving water. The position of the oil in the dome under varying conditions and experiments showing the effect of gas under similar conditions are described. Conclusions and inferences from the experiments are given.

INTRODUCTION

This paper presents the results of some experimental work intended to test in part the hydraulic theory of oil migration and accumulation by means of the downward circulation of water. The purpose of the experiments was threefold: (1) to determine if moving water would carry oil downward in a sand stratum and if so, to determine where the oil would accumulate; (2) to determine if possible the slowest rate of water flow necessary to produce downward migration of oil in a sand bed; and (3) to determine the effect of gas on oil moving downward under the influence of an hydraulic current.

For suggestions in the development of the experimental work, the author is indebted to Dr. W. H. Twenhofel, professor of geology at the University of Wisconsin. The oil was kindly furnished by Mr. R. E. Humphreys, of the Standard Oil Company, Whiting, Indiana. The experimental work was done at the University of Wisconsin during the academic year 1923–24.

[1] Introduced by C. Max Bauer and C. M. Rath.

DESCRIPTION OF APPARATUS AND MATERIALS

The apparatus used in the experiments to be described consisted of a plate-glass tank 72 inches long, 16 inches wide, and 19 inches high, with outlet arranged as shown in illustrations. The oil used was mid-continent crude, 35.5 Baumé. Screened aqueo-glacial sands from Janesville, Wisconsin, with a porosity of 40 per cent were used. Table I shows a screen analysis of the sand made with Tyler's standard screens. A small amount of copper sulphate was added to the water to inhibit the growth of organisms.

TABLE I

SCREEN ANALYSIS OF SAND USED IN EXPERIMENTS

Size in Millimeters	Mesh of Screens		Percentage
	Passed Through	Retained On	
0.883	20	28	19.5
0.589	28	35	47.0
0.417	35	48	19.8
0.295	48	65	8.6
0.208	65	80	4.0
0.175	80	....	1.1

METHOD OF OBTAINING THE POROSITY OF THE SAND

The porosity was calculated according to the formula

$$P=\frac{VD-W}{100VD},$$

where P equals the porosity, V the volume in centimeters, W the weight of the given volume, and D the mineral specific gravity of the sand. The mineral specific gravity was obtained by means of the pycnometer bottle. Care was taken to remove all the air bubbles included among the mineral particles by placing the pycnometer bottle and its contents of water and sand under the air pump and exhausting the air.

METHOD OF OBTAINING RATE OF WATER FLOW THROUGH SAND

The rate of water flow through the sand was calculated according to the formula

$$V=\frac{Q}{A},$$

where V equals the velocity, Q the quantity of water emitted per day, and A the cross-sectional area of the total pore space. In this calculation it is assumed that the water makes use of all the pores in its migration through the sand. In order to produce as uniform a water movement as possible through the sand, a screen box containing coarse sand was placed at the outlet end of the sand seam, thus producing a cliff effect.

EXPERIMENT I

The apparatus was arranged as shown on Figure 1, which is a view of the front side. A 2-inch sand bed, bounded on both top and bottom by clay, was built in the tank as shown in the figure. The dome, or really section of a dome, has a closure of 9 inches and slopes from front to back so that the highest point on the front side is 2 inches higher than the highest point on the back side. The dip from the intake to the right syncline is 19°. The highest part of the dome is 7 inches lower than the intake and 5 inches higher than the outlet, thus no water added to the sand could accumulate on the top of the dome. The upper part of the sand seam was kept open. Water was added at the intake end, and after it had passed into and part of it through the sand, the upper few inches of the sand at the intake were saturated with oil. The space above the sand as well as above the clay was filled with water and kept thus during the progress of the experiment.

Figure 1 shows the apparatus at the start of the experiment on January 10, when with a 12-inch head the water flowed through the sand at an average rāte of 6 feet per day. Oil was carried downward slowly, across the lower part of the dome to the outlet side where it tended to accumulate as shown in Figure 2, which indicates the progress of the oil by January 24. Some of the oil was carried beneath the second syncline and was emitted at the outlet with the water. During this time no additional oil was added to the sand.

On January 24, the outlet was raised so that it was at an elevation 1 inch higher than the top of the dome. The water now had a head of 6 inches and flowed through the sand at an average rate of 4 feet per day. From time to time, small amounts of oil were added to the sand at the intake, and within forty-eight hours the greater

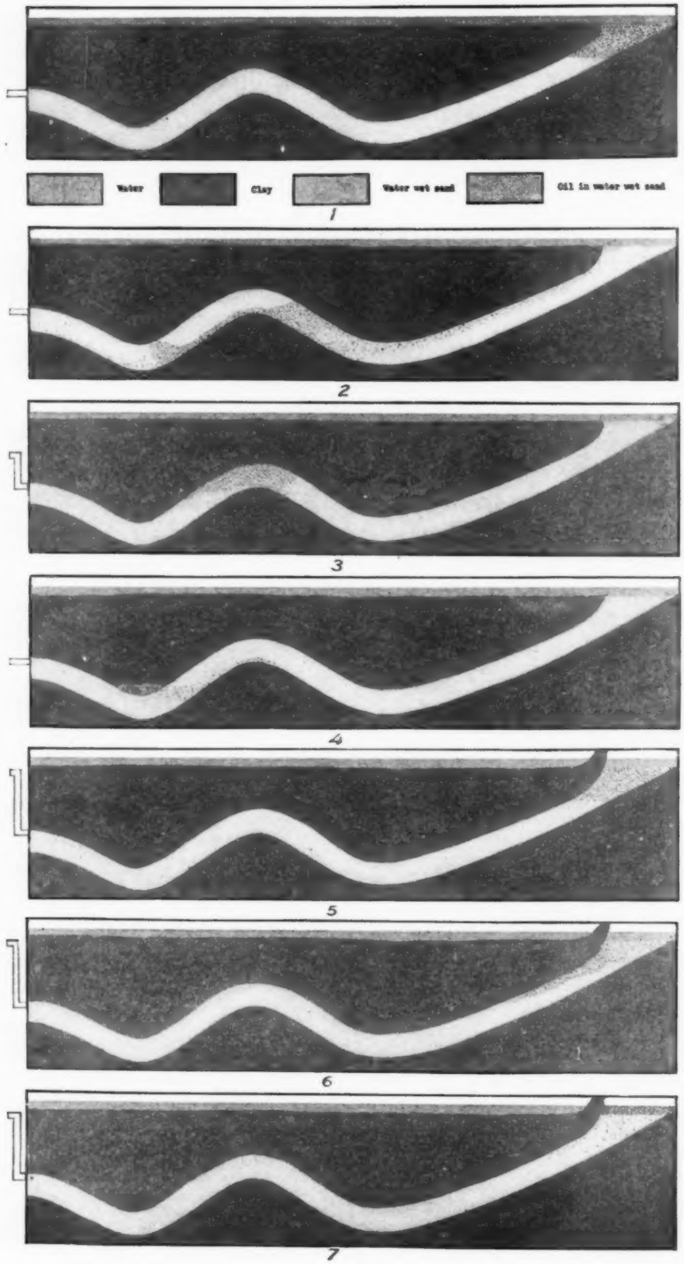
Water
Clay
Water wet sand
Oil in water wet sand
1
2
3
4
5
6
7

FIG. 1.—Diagram showing the position of the oil at the start of the experiment on January 10.

FIG. 2.—Position of oil on January 24. Outlet 5 inches lower than top of dome, thus the upper part of sand at top of dome is not saturated with water. Some oil was emitted at the outlet. Rate of water flow was 6 feet per day.

FIG. 3.—Position of oil on February 12. Outlet raised on January 24 to elevation 1 inch above top of dome. During this period oil was added at the intake and some oil dropped at the outlet. Water flow was 4 feet per day.

FIG. 4.—Position of oil on February 29. On February 12, the outlet was lowered to elevation 5 inches below top of dome. Oil lowered from top of dome to water level and dropped at the outlet at an increased rate. On February 28, the cavity at left syncline was formed artificially. It filled with oil in 24 hours. Water flow was 6 feet per day.

FIG. 5.—Position of the oil at the start of the second experiment on March 4. Outlet ½ inch lower than top of sand at intake. Sand contains 5 per cent of crushed limestone.

FIG. 6.—Position of oil on March 29. Water passed through the sand at approximately .50 of a foot per day. Oil migrated 15 inches down the 19 degree slope in 25 days.

FIG. 7.—Position of oil on April 5. On March 29, water acidified with HCl was added at the intake. Sand seam contained 5 per cent of crushed limestone. The gas generated forced the oil upward. Rate of water flow was increased from .50 to 6 feet per day during the progress of the experiment.

portion of it had migrated to the top of the dome. This indicated that once oil had passed through the sand any additional oil added to the intake could be carried by the moving water rather rapidly.

Figure 3 shows the progress of the oil by February 12. Much of the oil that had accumulated on the outlet side of the dome as shown in Figure 2 remained in that position. Some was carried downward under the syncline and was emitted at the outlet.

During previous preliminary experiments oil had become mixed with some of the clay which was later used in the upper clay seam of this experiment. Figure 2 shows the oil segregated in small patches in the clay. When the picture was taken, it had not yet segregated out. It is possible that it segregated from the water-wet clay by capillarity.[1]

On February 12, four holes at equally spaced intervals across the dome from front to back were drilled to the sand. Approximately

[1] In a road cut up the San Juan River Valley near Mexican Hat, Utah, built for the purpose of moving drilling machinery and supplies to near the crest of East Anticline, cavities in the limestone were observed filled with oil. It is believed that the oil segregated in the larger openings from pores in the surrounding rock.

one quart of oil was recovered in this manner. The hole nearest the top of the dome yielded the greatest amount of oil while the hole structurally lowest yielded mostly water. Within twenty-four hours after the wells were drilled, they went to water. However, at irregular-spaced intervals, globules of oil, no doubt carried by the water, would float to the top of the water-filled holes.

On February 14, the outlet was lowered to its former level so that the water had a head of 12 inches. The water gradually lowered from the top of the dome, assuming the position in the structure as shown in Figure 2. Oil dropped at the outlet with the water in increased amount. By February 28, while much of the oil had been flushed through, some was still retained on the outlet side of the dome.

In the process of removing the contents of the tank, preparatory to building the form for the experiment to follow, the clay-sealing layer above the sand in the right syncline was raised so that a cavity ($3\times3\times1$ inches) formed between the sand and the clay. The cavity immediately filled with water, and through the glass the oil could be seen moving downward and forward in globules into the cavity which was entirely filled within twenty-four hours (Fig. 4). Water was allowed to run through the sand for eight more days, and while oil was continually being flushed from the cavity, more was being added. It is believed that, in time, all the oil could have been flushed from the sand, but time would not permit the experiment to run any longer.

This was the first time that an opportunity was afforded to view the actual flow of oil, globule by globule, through the sand, in spite of careful searching day after day to detect such a movement. The reason for this was, no doubt, the slowness of the oil movement through the sand.

When the apparatus was taken apart, some oil was scattered through the whole system, but the greater amount was concentrated on the outlet side of the dome at about the level of the water in the syncline. The fact that the oil was scattered through the whole sand layer indicated that flow took place through the whole system rather than in separate channels.

A portion of the sand through which the oil had passed was

placed in a vessel, water added, and the whole was well shaken. The water and oil were then drained away, and the sand, after being dried, was examined under the microscope. No oil-coated sand grains could be detected.

EXPERIMENT II

The same type of sand used in Experiment I was used, except that about 5 per cent of crushed limestone, with the same screen analysis as the sand used in the previous experiment, was added to the sand. The outlet was raised to an elevation $\frac{1}{2}$ inch lower than the top of the sand at the intake. Water was added to the sand until the whole system was saturated. Two quarts of oil were added, and after it had passed into the upper part of the sand, water was introduced at the intake through a glass-stoppered cock which could be so regulated that rates of flow through the sand of less than 0.5 foot per day could be obtained. Figure 5 shows the apparatus at the start of the experiment on March 4. The calculated rate of water flow through the sand never exceeded 0.5 foot per day.

By March 29, the oil had migrated down the 19° slope a distance of 15 inches, as shown in Figure 6. On this date, water containing 2 per cent of hydrochloric acid was introduced at the intake. The gas generated forced the oil upward. The rate of flow was gradually increased to 6 feet per day, but as the acidified water gradually worked downward and generated gas when in contact with the limestone, the oil was forced upward against the downward flow of water. Most of the oil was carried back up the slope by April 5, as shown in Figure 7.

CONCLUSIONS

It must be remembered that these experiments represent a specialized case and cannot be construed as covering all cases. With this in mind, the following conclusions and inferences were reached for similar cases in nature.

1. Oil can be carried downward through a sand stratum by slow, downward-moving water.

2. In a homogeneous sand bed not cut by faults or other obstructions to migration other than that given by the sand itself,

moving water will tend to collect the oil in the upper part and outlet side of a dome.

3. Any variations in the texture or structure of a sand may cause oil accumulation in other parts of the sand.

4. Once oil has passed through a sand, additional oil added at the intake can be carried rather rapidly by downward-moving water. It appears that this fact would have an important application in nature as oil passing from a source rock into a sand would probably enter the sand in a great number of places from the syncline to the top of the dome. The sand would thus afford a medium through which comparatively rapid movement of oil could take place under the influence of hydraulic currents.

5. While part of the oil will tend to collect in those parts of the sand where textural or structural irregularities exist, some oil will be flushed through the sand with the water. In a continuous bed of wide extent, this oil would probably collect in other structures along the path of circulation.

6. The effect of gas is to carry the oil upward. It thus aids the force of buoyancy of the oil in resisting the downward force of the water caused by its velocity. In the experiment where gas was used, the oil was carried upward against a current of downward-moving water. It is probable that the gas pushes the oil upward, that part of the oil is carried as films on the gas bubbles, and that the expanding gas causes a local disturbance in the water which aids in freeing the oil globules from the openings between the sand grains.

7. In either upward or downward migration of oil, many factors hinder the movement, but one of the greatest obstacles to migration is the force required to distort the oil globules from the rounded shape they tend to assume in the spaces between the sand grains to the shape necessary to allow them to pass from one space to another. In upward migration, the buoyancy of the oil aids the force of the water; in downward migration, buoyancy retards it.

In the calculations of the rates of water flow, errors may occur because of the assumption that the water made equal use of the entire pore space in its migration through the sand. At times in the latter experiment, rates of flow as low as 0.05 foot per day were obtained, but temperature changes and difficulties in obtaining a con-

stant rate of water flow into the sand caused variations in the results from time to time. For example, it was found that the water moved faster during the day than at night, and on a warm day faster than on a cold day. However, during the whole time of the latter experiment when slow rates of water movement were used, the rate of flow as calculated never exceeded 0.5 foot per day.

It appears that there may be great variations in the rate of water movement through the various parts of an artesian basin, as fissures of all rocks probably participate in the horizontal movement of ground waters if they are in any way connected with the water-bearing stratum. The greater amount of the circulation probably occurs around the periphery. Circulation would be faster in the rocks having the larger pores and joints and slower in those with smaller openings. The porosity and size of grain of most sandstone beds, however, is much lower than that of the sand used here and varies in different areas.

To carry this work to its logical conclusion, it would be necessary to experiment with different types of sand and oil, and with varying degrees of slope. Thus by varying each of these factors in turn and keeping the others constant, it might be possible, with careful work, to determine the slowest rate of flow necessary to obtain downward migration of oil. Because of the slowness of the water flow it would be necessary to extend these experiments over a period of years.

Under the hydraulic theory of oil migration and accumulation, it does not suffice to map a few square miles of structure and write a report on the stratigraphy and oil prospects. It is necessary to study the major features of the structure, stratigraphy, physiography, conditions of sedimentation, and direction and rate of water flow of the entire region or province under consideration. Once the major features are well in mind, the details will tend to fall in order and be more easily solved.

THE AGE AND CORRELATION OF THE CHALK AT WHITE CLIFFS, ARKANSAS, WITH NOTES ON THE SUBSURFACE CORRELATIONS OF NORTHEAST TEXAS[1]

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ABSTRACT

The micro-fauna found in the chalk at White Cliffs, Sevier County, Arkansas, in the chalk at Rocky Comfort, Little River County, Arkansas, in the chalk at Clarksville, Red River County, Texas, and in the Pecan Gap chalk of Texas is the same and is Upper Taylor in age. Neither the Austin chalk nor Stephenson's Annona tongue of the Austin are present on the surface in northeast Texas east of Lamar County and in the wells east of Lamar and Hopkins counties. The sands which occur in the wells in northeast Texas below the Austin chalk and the Brownstown formation and which commonly have been called "Blossom" are Veatch's sub-Clarksville sands and are Upper Eagle Ford in age. The true Blossom sands, which are exposed at Blossom and Paris, Texas, are equivalent to the upper part of the Austin chalk.

INTRODUCTION

The chalk forming the cliffs on Little River at White Cliffs, Sevier County, Arkansas, has the same micro-fauna as is found in the Pecan Gap chalk of Texas, which Stephenson[2] places at the top of the Taylor marl. The chalk at White Cliffs was originally named the "White Cliffs" chalk, and later the Annona. Stephenson[3] has correlated it with his Annona tongue of the Austin chalk, stating that the Annona chalk exposed at Clarksville disappears under the alluvium of Red River, but appears again at Rocky Comfort and is well exposed on the river at White Cliffs.

Subsurface work in northeast Texas has shown that three chalks are present in the counties south of Delta: (1) the Pecan Gap chalk, (2) a chalk in the Taylor marl commonly called "Annona chalk," and (3) the Austin chalk. The so-called "Annona" chalk and the

[1] The data presented in this paper were obtained at the expense of the Humble Oil and Refining Company through the organization of its geological department and are released for publication by the officers of that company.

[2] *U. S. Geol. Survey Prof. Paper 120*, p. 152.

[3] *Loc. cit.*

Austin chalk disappear in the wells east of Hopkins County, and the Pecan Gap chalk becomes thicker in southern Hopkins and Van Zandt counties and to the east of Hopkins County. In Bowie County the well logs show that the Pecan Gap chalk becomes 400 feet thick. In the southern part of Hopkins County and Van Zandt County about 200 feet of Pecan Gap chalk is present in some wells.

FIELD WORK

Mr. L. P. Teas, district geologist for the Humble Oil and Refining Company, at Shreveport, assisted the writer in obtaining samples of the outcrops and in studying the sections. Field trips were made with Mr. Teas to obtain sections in southern Arkansas, from Saratoga north to Mineral Springs, from White Cliffs north to Brownstown and Ben Lomond. Mr. Teas made the section from Rocky Comfort north to Arkinda. In Texas we made sections of the formations in discussion in Red River, Lamar, Delta, Fannin, and Hunt counties. Mr. G. Moses Knebel, geologist for the Humble Oil and Refining Company, made a complete section of the Pecan Gap in Falls County. Outcrop samples of all the formations in discussion were studied for microscopic fauna. Complete sets of samples from wells were also analyzed. The microscopic fauna present in the beds at the type localities of each formation have been found to be the same. The data available proves conclusively that the Foraminifera have an extensive geographic range, but a limited vertical range. For these reasons they are very good index fossils for correlating these formations.

HISTORY

As noted, the chalk forming the bluffs of Little River at White Cliffs, Arkansas, was originally called "White Cliffs" by Hill.[1] In the same paper Hill defined the "Rocky Comfort" chalk, which he did not recognize as the same as the chalk at White Cliffs. In 1901 Hill[2] renamed the White Cliffs chalk the Annona chalk, from the town of Annona in Red River County, Texas. He says: "The chalky (Anona) beds [the White Cliffs chalk of the writer's Arkansas section] outcrop at Clarksville and thence via Paxton and Honey

[1] *Arkansas Geol. Survey Annual Report for 1888*, Vol. 2, pp. 87–89.

[2] *U. S. Geol. Survey, Twenty-First Annual Report*, Part 7, p. 341.

Grove nearly to Bonham, but are not known south of these points. The writer has considered this chalk to represent a higher horizon than the Austin chalk, but its exact relationship is subject to future determination."

The Pecan Gap chalk, the chalk at Clarksville, the chalk at Rocky Comfort, the chalk at White Cliffs are all the same chalk, and accordingly the question of the name has arisen. The chalk, which is rightfully named "Pecan Gap" in Texas, is called "Annona" in Louisiana and Arkansas. This name is inappropriate because the chalk does not outcrop at Annona, Texas, but at Clarksville and White Rock, farther north. Also the name Annona has become identified with the chalk which is Stephenson's tongue of the Austin chalk, and to apply this name to the Pecan Gap beds will confuse the latter with the much older chalk. Stephenson[1] states that "the section at White Cliffs, Arkansas, should continue to be regarded as the type locality of the division." The author has considered reviving Hill's name of "White Cliffs" chalk, but because Powell[2] had used this name for certain Jurassic beds in Utah, Hill changed the name to Annona, which, as stated previously, is inappropriate. The name "Pecan Gap chalk" is accepted in the literature and is familiar to geologists. The author believes that the name "Pecan Gap" is preferable, for the reasons given, and proposes that it be accepted for the chalk at White Cliffs.

THE CHALK AT WHITE CLIFFS

Taff[3] describes the exposure of chalk at White Cliffs' landing on Little River as follows:

	Feet
1. Massive, creamy-white chalk, in beds from 1 to 10 feet thick, separated by thin partings of very slightly laminated chalk............	60
2. Massive, dull bluish-white siliceous chalk, slightly harder than the pure chalk of 1. This chalk is practically without indication of bedding, and because of its hardness it projects in a steep bench overhanging the less chalky and friable beds below..................................	25

[1] *U. S. Geol. Survey Prof. Paper 120* (1918), p. 151.

[2] "Geology of Uinta Mountains," *U. S. Geog. and Geol. Survey Terr.* (1876), pp. 41, 51.

[3] J. A. Taff, *Twenty-Second Annual Report U. S. Geol. Survey*, Part 3 (1902), pp. 706–7.

	Feet
3. Massive, very siliceous, dull-blue argillaceous chalk marl. This bed contains more than twice as much sand, and nearly three times as much clay, as the overlapping bed. The rock is very friable and weathers in recesses beneath the siliceous chalk	8
4. Bluish, sandy, chalky marl, containing great numbers of fossil shell *Gryphaea vesicularis* var. Except for the abundant fossils, this rock would be classed with 3, though it is probably slightly more sandy	7
5. Bluish, sandy marl, gradually increasing in sandiness from the top downward to the level of the river. This bed contains *Gryphaea vesicularis* var., but not in such abundance as 4; also many fossils of the large and heavy oyster *Exogyra ponderosa*, as well as others common to the Upper Cretaceous marls	35

The hard white chalk in the upper 60 feet of the section contains the same association of Foraminifera as found in the upper part of the Pecan Gap chalk in Texas near Pecan Gap and 1.8 mile south of Ladonia, and in the top of the Pecan Gap chalk in the wells in northeast Texas. No critical study of the Foraminifera, many of which are new species, has been made, but the forms listed have been compared with the nearest described species, and will serve for the purpose of comparing this locality with others.

FORAMINIFERA OF THE UPPER 60 FEET OF THE PECAN GAP CHALK AT WHITE CLIFFS, ARKANSAS

Truncatulina cf. *refulgens* Montfort
Bulimina cf. pupoides d'Orbigny
Pulvinulina sp.—highly ornamented form
Cassidulina cf. *subglobosa* Brady
Truncatulina sp.—locally named "rosetta"
Bolivina sp.
Truncatulina wuellerstorfi Schwager
Bolivina sp. A
Rotalia exsculpta Reuss
Truncatulina akneriana d'Orbigny
Truncatulina ungeriana d'Orbigny
Frondicularia sp. A
Rotalia soldanii var.
Nodosaria sp.
Pulvinulina truncatulinoides d'Orbigny
Globigerina sp.
Clavulina parisiensis d'Orbigny

The light blue chalk about 45 feet above the river, which carries *Gryphaea vesicularis* var. and *Exogyra ponderosa*, and is so highly fossiliferous as to have the appearance of a sandy chalk, contains a more abundant foraminiferal fauna than the overlying members, and is the same as found in the Pecan Gap chalk outcropping at the following localities: the Falls of the Brazos River, near Marlin; $3\frac{1}{2}$ miles south of Bairdstown; 2 miles north of Enloe; 3.6 miles northeast of Enloe; $1\frac{1}{2}$ miles south of Ladonia; and 5 miles south of Wolfe City on the Wolfe City and Greenville road. In addition to the fauna listed above, this chalk includes species resembling the following described forms.

Frondicularia sp. B
Nodosaria sp. B
Lagena cf. *aspera*
Ammobaculites cf. *agglutinans*
Truncatulina sp.—locally named "taylorensis"
Discorbis sp. A
Frondicularia rugosa d'Orbigny
Anomalina sp.
Lagena sp. B

In the quarry a little southeast of this exposure on Little River an excellent section of the chalk was seen. About 20 feet below the top of a hard white chalk numerous casts of a very large species of *Inoceramus* were found. The association of Foraminifera is the same as that in the upper part of the chalk forming the cliffs, and the same as found in the upper part of the Pecan Gap of Texas. About 60 feet below this hard white chalk is a light blue-gray marl above a zone carrying a great number of *Gryphaea vesicularis*. This zone contains the same fauna as that in the *Gryphaea vesicularis* zone of the White Cliffs section.

THE CHALK AT ROCKY COMFORT

Beds of massive white chalk, which is a pale blue before weathering, are exposed along the road at Rocky Comfort, $1\frac{1}{2}$ miles southwest of Foreman, Little River County, Arkansas. The bedding is generally massive, although the upper layers are thinly bedded. The fossils are poorly preserved, but imprints of large species of *Inoceramus* and casts of *Baculites* were noted in the massive white

chalk. The micro-fauna is the same as that found in the chalk in the quarry and bluff at White Cliffs. At locality 126 E (see map, Plate 20) we found a specimen of *Ananchytes texana* Cragin, which is also found in the chalk at Clarksville, Texas. Mr. Robert L. Cannon reports finding this same fossil in the Anacacho formation, 75 feet below the *Exogyra costata* zone of the Navarro, in Medina County, Texas. At White Hill, 2.9 miles southwest of Rocky Comfort, occurs a pure white, massively bedded chalk 25 feet thick, which grades down into a pale blue marl weathering into a light buff color. This marl is the Marlbrook. The chalk above it contains a micro-fauna similar to that of the Saratoga chalk of the Marlbrook.

THE CHALK NORTH OF SARATOGA

On the Mineral Springs–Saratoga road, about two miles north of Saratoga, Howard County, Arkansas, is an exposure of hard white chalk which is a pale blue before weathering. This chalk is characterized by the same association of Pecan Gap Foraminifera as that found in the top of the chalk at the cliffs and quarry, in the chalk at Rocky Comfort, and in the chalk at the type locality of the Pecan Gap of Texas. This outcrop of chalk lies immediately below a dark blue, massively bedded clay, weathering to a light yellow. The clay breaks with a conchoidal fracture and is highly calcareous. The presence of *Exogyra cancellata* and *E. ponderosa* var. *erraticostata* and the large species of *Gryphaea vesicularis* place the age of these blue clays as the lower part of the Navarro or Marlbrook. The Foraminifera are Navarro in age.

The base of the Saratoga chalk occurs 90 feet above this clay. In this basal chalk occur *E. cancellata* and the large species of *G. vesicularis*, and in the upper part, numerous specimens of *E. costata* and *G. vesicularis*. The Foraminifera are very abundant.

THE BROWNSTOWN

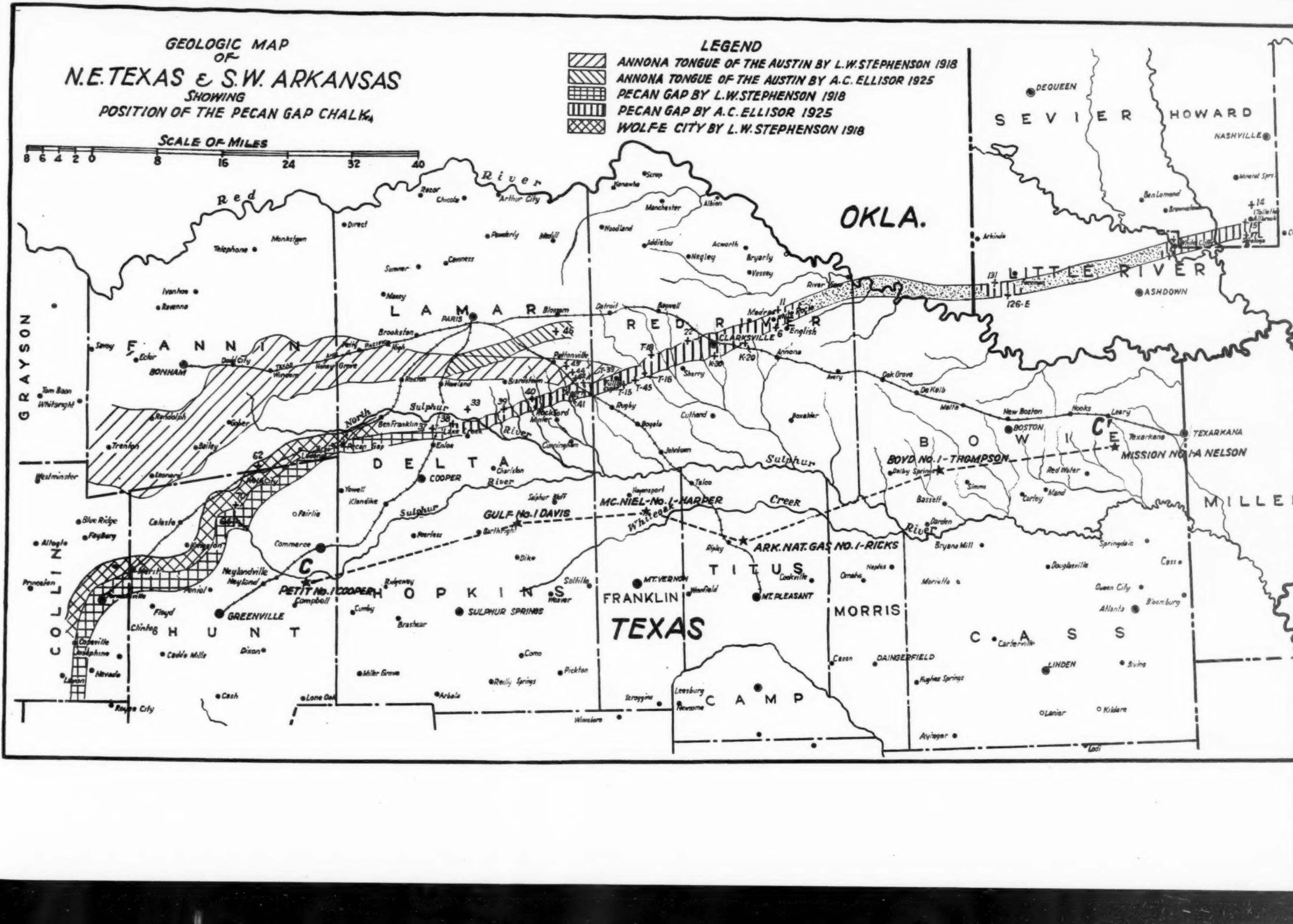
Veatch[1] states that the "Brownstown formation into which the Bingen sand grades is well developed in the southern part of Sevier County, Arkansas, about Brownstown, from which place it takes its name. It is a blue or gray calcareous clay containing many fossil

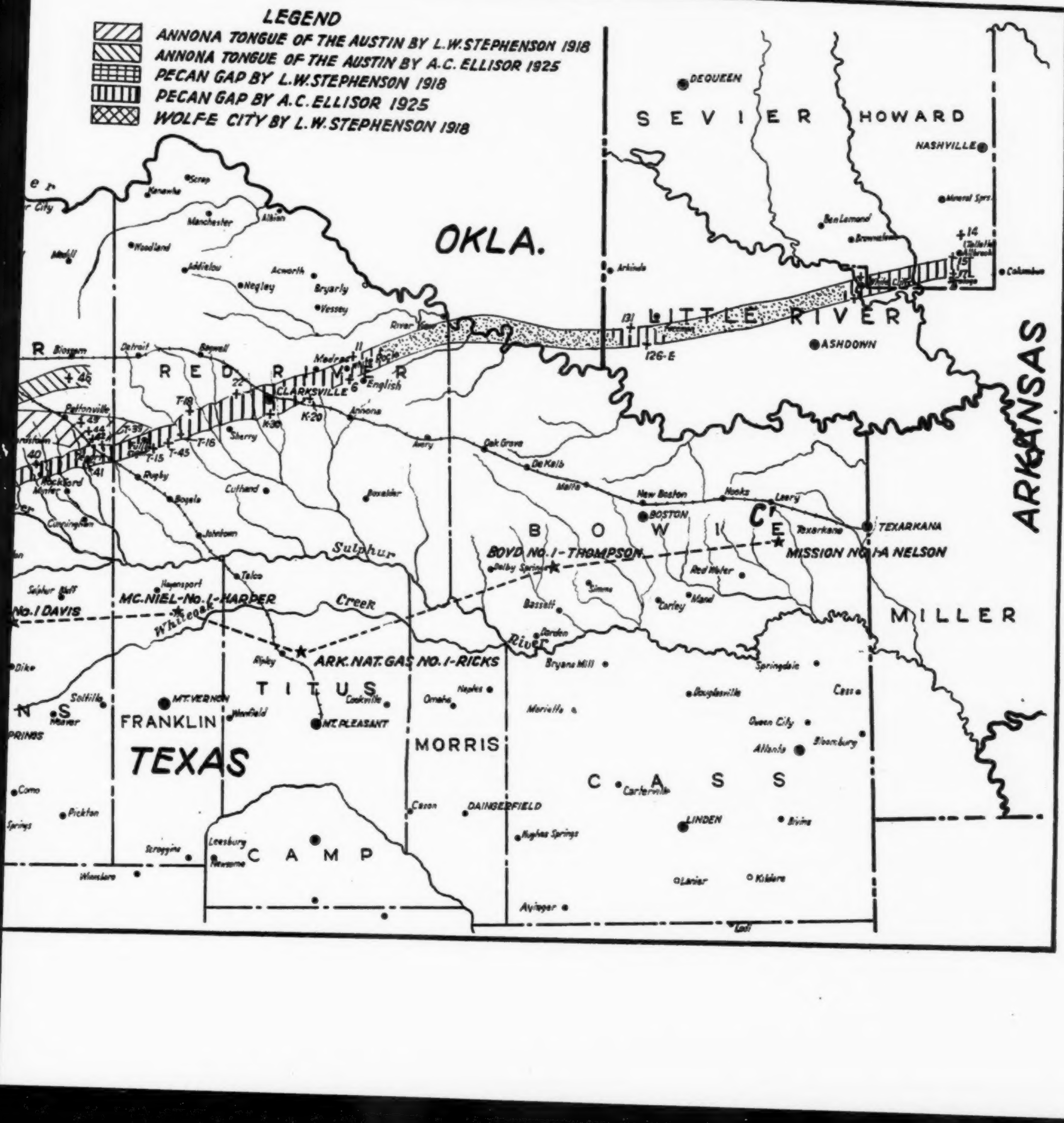
[1] A. C. Veatch, *U. S. Geol. Survey Prof. Paper* 46, p. 25.

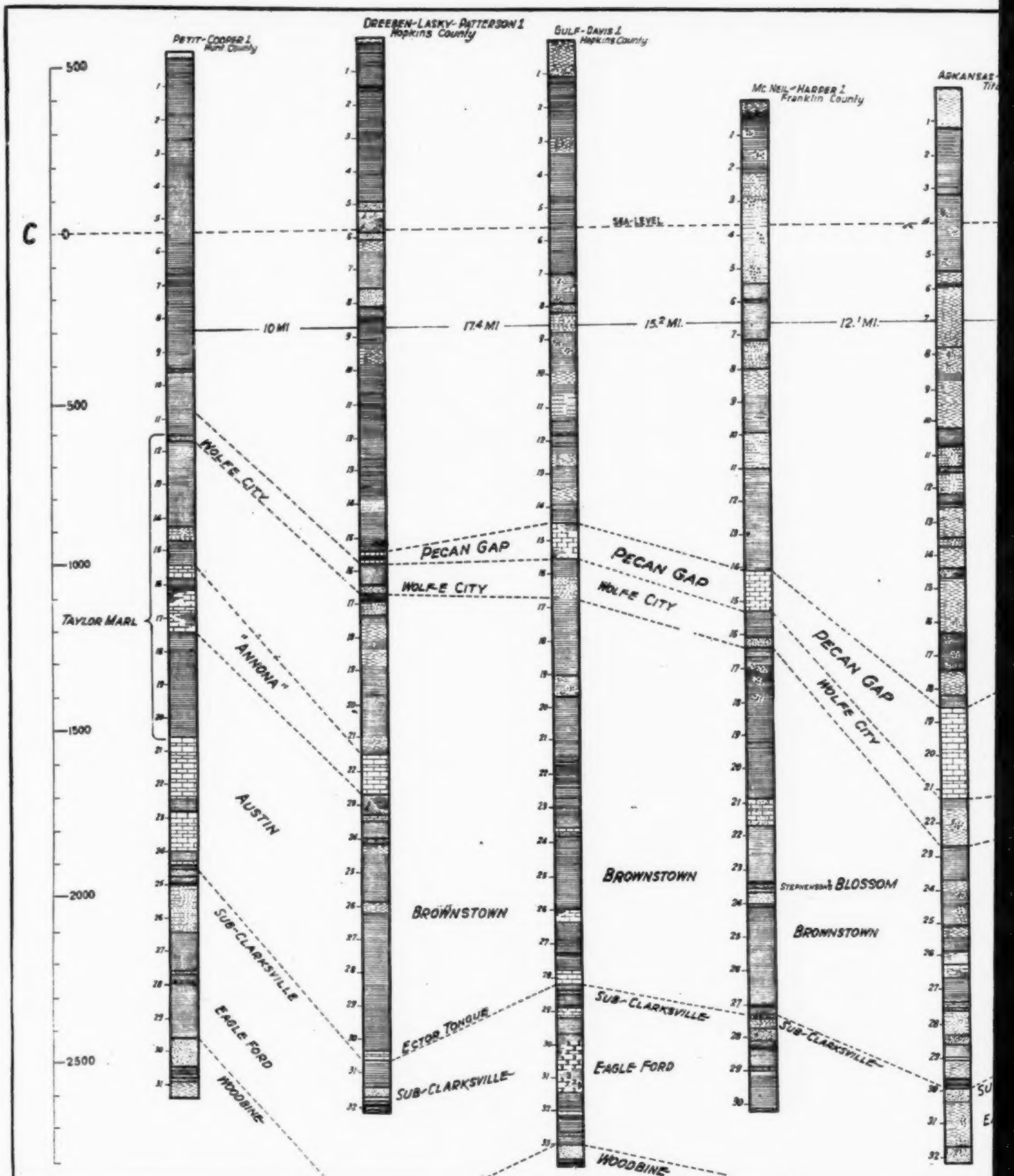
oysters, and is characterized by the presence of the large oyster *Exogyra ponderosa*, whence it has been called the *Exogyra ponderosa* marl. About half a mile south of Brownstown, along the White Cliffs road, is an outcrop of a highly calcareous, clayey, glauconitic sand which weathers light yellow. Lenses of quartz sand with considerable glauconite occur in less sandy blue-gray clay which weathers to a light yellow or drab. Similar beds outcrop about a mile west of Brownstown, about a mile north of Tollette in Howard County, Arkansas, and on the Saratoga-Mineral Springs road, Locality 14 on map (Plate 20). Below the chalk at Rocky Comfort on the Foreman-Arkinda road, $3\frac{1}{2}$ miles northwest of Foreman, Arkansas, is a sandy glauconitic clay with the same fauna. This same fossiliferous sand occurs north of Okolona, Arkansas, in Section 27-8-22, just below the Pecan Gap formation which is represented by a sandy chalk. The noticeable feature of this sand is the abundance of fossils. The following species were collected from Locality 14 on the Saratoga-Mineral Springs road.

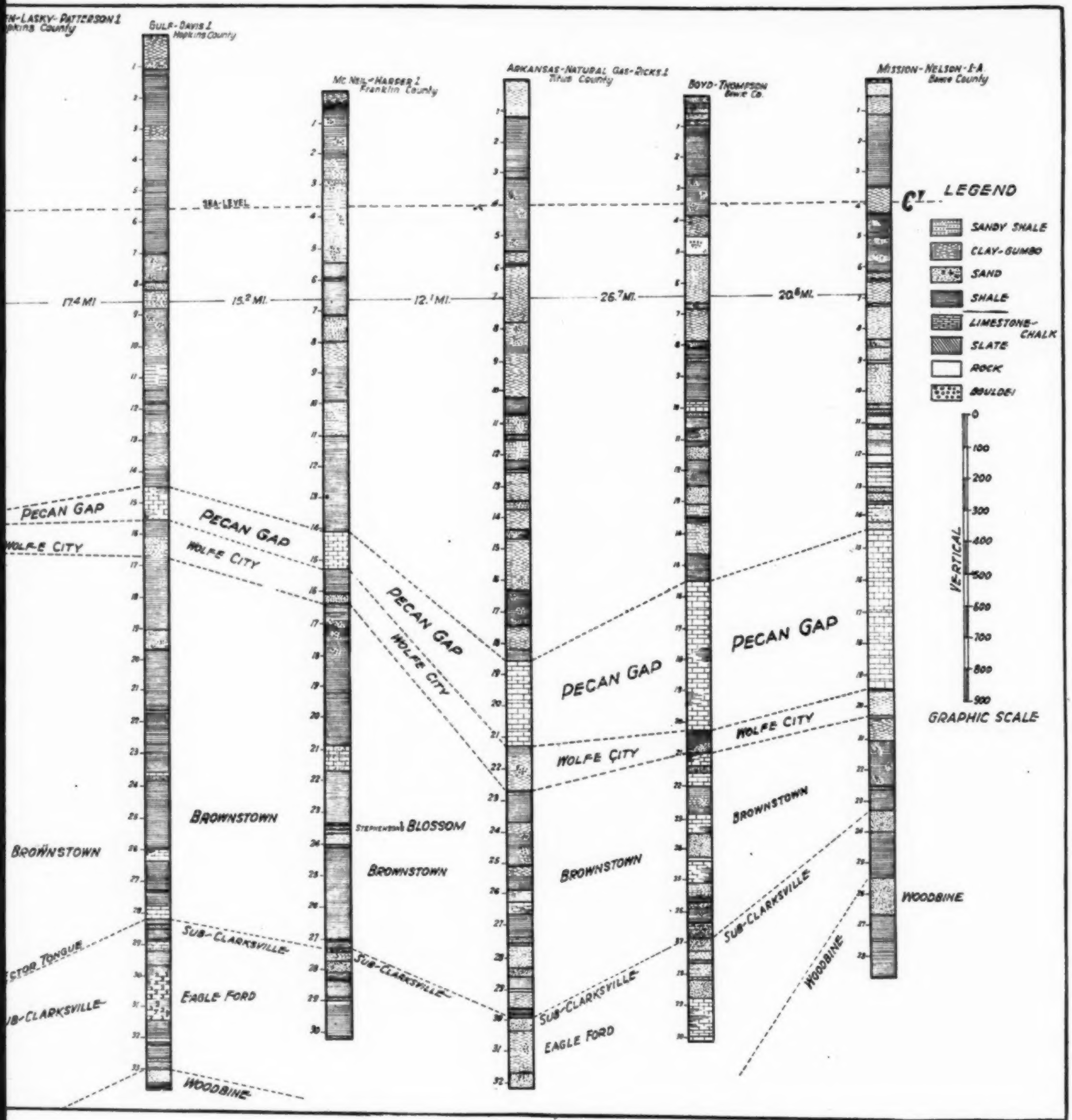
FAUNA OF THE BROWNSTOWN BEDS, ON THE SARATOGA-MINERAL SPRINGS ROAD

Exogyra ponderosa, Roemer large species
Exogyra ponderosa var. *erraticostata* Stephenson
Exogyra nov. sp. (?) small ribbed species, possibly a young species of *Exogyra costata*
Exogyra sp.
Ostrea falcata (larva) Morton
Paranomia scabra Morton
Pecten casteeli Kniker (*P. Quinquecostata*)
Hamulus major Gobb
Hamulus squamosus var. *rugosus* n. var. Stephenson
Anomia argentaria Morton
Ostrea plumosa Morton
Baculites ovatus (Same as figured in Maryland Report of Cretaceous, page cix)
Serpula sp.
Casts of Gastropods
Corals
Shark teeth
Foraminifera


GEOLOGIC MAP
OF
N.E. TEXAS & S.W. ARKANSAS
SHOWING
POSITION OF THE PECAN GAP CHALK
LEGEND
ANNONA TONGUE OF THE AUSTIN BY L.W. STEPHENSON 1918
ANNONA TONGUE OF THE AUSTIN BY A.C. ELLISOR 1925
PECAN GAP BY L.W. STEPHENSON 1918
PECAN GAP BY A.C. ELLISOR 1925
WOLFE CITY BY L.W. STEPHENSON 1918
SCALE OF MILES
8 6 4 2 0 8 16 24 32 40
OKLA.
TEXAS
Red River
LITTLE RIVER
SEVIER
HOWARD
GRAYSON
FANNIN
LAMAR
RED RIVER
BOWIE
MILLER
DELTA
HOPKINS
HUNT
COLLIN
FRANKLIN
TITUS
MORRIS
CAMP
CASS
PARIS
BONHAM
CLARKSVILLE
COOPER
GREENVILLE
SULPHUR SPRINGS
MT. VERNON
MT. PLEASANT
TEXARKANA
BOSTON
DEQUEEN
NASHVILLE
ASHDOWN
LINDEN
DAINGERFIELD
GULF No. 1 DAVIS
MC.NIEL No. 1-HARPER
ARK. NAT. GAS NO. 1-RICKS
BOYD NO. 1-THOMPSON
MISSION NO. 1-A NELSON
PETIT NO. 1 COOPER
Sulphur River
North Sulphur
Whiteoak Creek


LEGEND
ANNONA TONGUE OF THE AUSTIN BY L.W. STEPHENSON 1918
ANNONA TONGUE OF THE AUSTIN BY A.C. ELLISOR 1925
PECAN GAP BY L.W. STEPHENSON 1918
PECAN GAP BY A.C. ELLISOR 1925
WOLFE CITY BY L.W. STEPHENSON 1918
OKLA.
ARKANSAS
TEXAS
SEVIER
HOWARD
DEQUEEN
NASHVILLE
LITTLE RIVER
ASHDOWN
RED RIVER
CLARKSVILLE
BOWIE
BOSTON
TEXARKANA
MILLER
BOYD NO. 1 - THOMPSON
MISSION NO. 1-A NELSON
MC. NIEL - NO. 1 - HARPER
No. 1 DAVIS
ARK. NAT. GAS NO. 1 - RICKS
Sulphur
Creek
River
TITUS
MT. VERNON
MT. PLEASANT
FRANKLIN
MORRIS
DAINGERFIELD
CASS
LINDEN
CAMP
Annona
De Kalb
New Boston
Hooks
English
Detroit
Atlanta
Queen City
Naples
Omaha
Talco
Rugby
Johntown


C
Petit-Cooper 1
Hunt County
Dreeben-Lasky-Patterson 1
Hopkins County
Gulf-Davis 1
Hopkins County
Mc Neil-Harper 1
Franklin County
Arkansas
Sea-Level
10 MI
17.4 MI
15.2 MI.
12.1 MI.
500
0
500
1000
1500
2000
2500
Taylor Marl
Wolfe City
Pecan Gap
Wolfe City
Pecan Gap
Wolfe City
Pecan Gap
Wolfe City
"Annona"
Austin
Brownstown
Brownstown
Stephenson's Blossom
Brownstown
Sub-Clarksville
Ector Tongue
Sub-Clarksville
Sub-Clarksville
Sub-Clarksville
Eagle Ford
Eagle Ford
Woodbine
Woodbine


Gulf-Davis 1
Hopkins County
Mc Neil-Harger 1
Franklin County
Arkansas-Natural Gas-Ricks 1
Titus County
Boyd-Thompson
Bowie Co.
Mission-Nelson-1-A
Bowie County
Sea-Level
17.4 Mi.
15.2 Mi.
12.1 Mi.
26.7 Mi.
20.6 Mi.
Legend
Sandy shale
Clay-gumbo
Sand
Shale
Limestone-chalk
Slate
Rock
Boulder
Vertical
Graphic scale
Pecan Gap
Wolfe City
Brownstown
Blossom
Sub-Clarksville
Eagle Ford
Woodbine

A similar association of fossils was found in the Wolfe City sands of Texas, $\frac{1}{4}$ mile north of Ladonia and $1\frac{1}{4}$ miles north of Wolfe City. The association of Foraminifera in these sands and clays of the upper Brownstown is the same as found in the Wolfe City formation of Texas, in the wells and from the outcrops near Wolfe City, Hunt County, Texas.

Below these sands and associated clays of the upper Brownstown and above the sand series of the Bingen are the clays of the lower portion of the Brownstown. These are blue-gray and dark blue-gray calcareous clays weathering to a dark olive green. The weathering of these lower clays is different from that of the upper clays, which have the characteristics of Taylor marl weathering. *Exogyra ponderosa* and *E. ponderosa* var. *erraticostata* occur in these lower clays, and the Foraminifera are different from those in the upper part of the clays.

THE PECAN GAP CHALK OF TEXAS

Having found that the chalks outcropping at Rocky Comfort, White Cliffs, and north of Saratoga are all the same, and are lithologically and paleontologically like the Pecan Gap chalk of Texas, and that the geologic section of southwestern Arkansas may be correlated with the well sections of the adjoining counties of Texas, plans were made to trace the outcrop of the Pecan Gap from the type locality across into Arkansas. The chalk, outcropping at Clarksville, Texas, which is the type locality of Hill's "Annona," is also exposed at White Rock, northeast of Clarksville, where a very good section can be seen. This chalk is light gray to light blue in color, weathering white. It is usually massive, with a few thin bedded layers. The megascopic fossils noted were: *Inoceramus* sp., *Pecten casteeli* Kniker (*quinquecostata*), *Baculites* sp., *Exogyra ponderosa* var. *erraticostata*. The chalk contains an abundance of Foraminifera and is the same horizon as that exposed $1\frac{1}{2}$ miles west of Deport, described below.

The chalk outcropping in the vicinity of Deport, Lamar County, Texas, which Stephenson[1] has mapped as the southernmost limit of

[1] L. W. Stephenson, *U. S. Geol. Survey Prof. Paper 120*, Plate 17.

his Annona tongue of the Austin, is the Pecan Gap chalk. An excellent exposure of this chalk is found in a creek bed $1\frac{1}{2}$ miles west of Deport, on the Milton-Deport road. Here the chalk is a light gray, weathering white. This locality shows numerous specimens of *Exogyra ponderosa*, *E. ponderosa* var. *erraticostata*, *Inoceramus* sp., *Gryphaea vesicularis*, cephalopods, *Baculites ovatus*, casts of gastropods and pelecypods. The lithology and fossils of this chalk are the same as those found at a locality 2 miles north of Enloe and 4 miles west of the Paris-Cooper highway, near the North Fork Sulphur River. The same chalk outcrops 3.6 miles northeast of Enloe, Texas, west of the Paris-Cooper Highway. The Pecan Gap chalk was also found $3\frac{1}{2}$ miles due south of Bairdstown, $2\frac{1}{2}$ miles northwest of Rockford, on the Bairdstown-Rockford road, in the vicinity of Rockford, and on the Tucker farm, about a mile west of Milton, all in Lamar County, Texas. The chalk was also traced west of Clarksville, toward Deport. Outcrops were noted at McCoy and along the road between McCoy and Scatter Creek. The chalk forms the banks of Scatter Creek, also the banks of the North Branch of Cuthand Creek, and the banks of Gouchy Creek near Gintown.

THE AREA NORTH OF DEPORT

The area north of Deport in Lamar County, Texas, as far as Pattonville, which Stephenson[1] maps as Annona, shows typical Taylor marl clays with nodules and lumps of calcium carbonate. These clays weather a light greenish-yellow. They contain *Exogyra ponderosa* and *E. ponderosa* var. *erraticostata*. Two miles north of Deport, on the highway to Pattonville, a sample of a light greenish-yellow, highly calcareous sandy clay from a 12-foot well contained the same Foraminifera as found in the Wolfe City formation. In a field half a mile north of this well the same light greenish-yellow sandy clays occur with numerous lime nodules, and the same two varieties of *Exogyra ponderosa* and *E. ponderosa* var. *erraticostata* occur in these sandy clays.

Two miles north of Pattonville, on the road to Blossom, the soil changes from the greenish-yellow of the Taylor formation to black, which is characteristic of weathered chalk. Three miles north of

[1] *Loc. cit.*

Pattonville was found a freshly dug pit in the chalk which showed a deep cream color with spots of iron-oxide stains and a lithology the same as that of the "Annona" chalk south of Paris and from the vicinity of Honey Grove. The chalk is not present in the area between Detroit and Clarksville in Red River County, Texas.

SUBSURFACE CORRELATIONS

The cross-section (Plate 21) along the line *CC′*, as shown on the map (Plate 20), through Hunt, Hopkins, Franklin, Titus, Morris, and Bowie counties, Texas, shows the variations in the formations in northeastern Texas below the Navarro formation.

In Hunt County there are three chalks. A generalized section of all the wells studied shows from 50 to 100 feet of Pecan Gap chalk, although the chalk is not logged in some of the wells. The log of the Petit No. 1 Cooper, one of the wells used in the cross-section, shows no Pecan Gap chalk. From 300 to 500 feet below the Pecan Gap chalk is the "Annona" chalk, averaging 150 feet thick. Here the term "Annona" is applied to the chalk in the Taylor. The Foraminifera found in the so-called "Annona" chalk in the wells are the same as found in Stephenson's Annona tongue outcropping in Lamar and Fannin counties. The Austin chalk occurs 250 to 350 feet below the "Annona," ranging from 400 to 500 feet thick, showing some shale breaks. A series of sands and shales occur below this Austin chalk and above the lower phase of the Eagle Ford shales, that is, the black bituminous fissile shales, having fish scales and numerous specimens of *Textularia globulosa*, *Trochammina* sp., and *Globigerina cretacea*, the Foraminifera being altered by pressure in most instances, to lumps of calcium carbonate, giving the shale a speckled appearance. The shales are non-calcareous, dark bluish-gray, micaceous and unctuous shales with a few fossils, such as fish scales, *Inoceramus* prisms, *Globigerina* and *Textularia* and a few arenaceous species. The sandstones are fine-textured glauconitic sandstones, sometimes showing a great deal of muscovite and biotite. The amount of glauconite varies from a few grains to a great deal, giving the sandstone the appearance of a greensand. Below the Eagle Ford shales occurs the Woodbine formation.

In the southwestern part of Hopkins County, and in north-

western Rains County, Texas, the geologic section is the same as in Hunt County, Texas. In the log of the Marland No. 1 Coppedge, which is taken as a representative well of this area, the Pecan Gap chalk becomes 200 feet thick, and below this chalk occur 200 feet of sand with shale breaks. Samples from this sand contain fossils characteristic of the Wolfe City. The "Annona" chalk in this well is 200 feet thick, and the Austin chalk, 400 feet thick. Below the Austin and above the black bituminous Eagle Ford shales occur glauconitic micaceous sandstones interlaminated with blue-gray non-calcareous micaceous shales. Farther east, in Hopkins County, the Pecan Gap chalk persists, the "Annona" becomes thinner, and the Austin chalk member is represented by the Ector tongue (50 feet thick) and possibly the lower part of the Brownstown formation.

In the Texas Company No. 1 Enix, Hopkins County, Texas, at 2,425 feet in a sandy clay below the Pecan Gap chalk, occurs the same association of Foraminifera as found in the Wolfe City sands, also like that found in the sandy clays at Locality 42 (Plate 20) just north of Deport, Texas, and in the glauconitic sands in the Brownstown at Locality 14 (Plate 20) on the Saratoga-Mineral Springs road, Howard County, Arkansas. The "Annona" occurs at 2,750 feet and is only 100 feet thick, while below this are 750 feet of dark blue-gray calcareous shaly clays with an occasional lense of chalk. The clays have the same Foraminifera as found in the lower Brownstown of Arkansas. A sample from 3,009 feet shows a fauna similar to that found in the Brownstown cropping out about one-half mile south of Ben Lomond, Arkansas, on the Ashdown road. Around 3,300 feet occurs a fauna similar to that found in the basal part of the Brownstown formation 1.4 miles north of Brownstown, Arkansas, also in the Brownstown 2 miles south of Paris, Texas, on the Cooper-Paris highway. Below these shaly clays occur 50 feet of chalk having the same fossils and lithology as the Ector tongue, beneath which is the same type of sands and shales as has been described below the Austin in the upper part of the Eagle Ford.

From the Gulf Company No. 1 Davis, between 1,900 and 2,000 feet, cuttings of a gray clay show some characteristic "Annona chalk" Foraminifera. Possibly this represents the "Annona" horizon, for below this point shales show a typical Brownstown fauna. The

Brownstown in this well correlates with that in the Enix well below the "Annona." At 2,135 feet begins the same fauna as found in the Brownstown one-half mile south of Ben Lomond on the Ashdown road, and at 2,400 feet begins the same fauna as found in the Brownstown 1.4 miles north of Brownstown, Arkansas. As in the Enix No. 1, these Brownstown clays are succeeded below by the Ector tongue of the Austin. Below the Ector tongue is the same type of sandstones as found below the Austin chalk—a glauconitic sandstone, interlaminated with blue-gray non-calcareous micaceous shales. These shales and glauconitic sands grade into the typical bituminous Eagle Ford shales, below which is the Woodbine formation.

East of Hopkins County, in the wells studied, no "Annona" or Austin chalks have been found, and the Pecan Gap chalk gradually thickens. In Bowie County the chalk is at least 400 feet thick. In the Mission Oil Company No. 1 A. Nelson, above the Pecan Gap chalk is the Saratoga chalk, with clays separating it from the Pecan Gap chalk. The clays have the same Foraminifera as in the Marlbrook. Below the Pecan Gap chalk occurs the Brownstown formation, a dark-gray calcareous clay. In the upper part of the clays there is a glauconitic sand, as in the section at the outcrop of the Brownstown in Arkansas, containing the same association of Foraminifera as in the Wolfe City formation. Below the Brownstown occurs the same type of sand and associated shales as found in the Upper Eagle Ford above the black bituminous Eagle Ford shales and below the Austin chalk in the western part of northeast Texas. As the typical black bituminous phase of the Lower Eagle Ford shales are missing in this area, these sands and shales grade into the Woodbine or Bingen, the Arkansas and Louisiana equivalent of the Woodbine.

These sands, which have been described as occurring below the Brownstown, and the Austin chalk in the wells in northeast Texas have been commonly called the "Blossom sands," but they are not the Blossom sands, the type locality of which is at Blossom, Lamar County, Texas. The true Blossom sands are much younger in age than these sands, Stephenson placing them as Upper Austin in age. The Sands which occur below the Brownstown are the same as those

found in the upper part of the Eagle Ford, just below the Austin chalk. These same sands can be traced in the wells from Hunt and Hopkins counties east to Bowie County, Texas. The writer has recently found *Ostrea lugubris* in sandstones outcropping at Woodland, also 2 miles south of Manchester, Red River County, Texas, just below the Brownstown marls. Here this oyster bed rested upon glauconitic sandstones with lignite. North of Woodland were the selenitic blue clays of the Eagle Ford with septaria, the same as found below the *O. lugubris* horizon in Fannin County, Texas. Below these clays occur the Woodbine, so well exposed at Pine Bluff. The *O. lugubris* zone of the Upper Eagle Ford has been found outcropping on the surface, at least as far as Red River County, east of Woodland. *O. lugubris* has also been found in wells in northeastern Louisiana.[1] This sand horizon in the wells below the Brownstown, which is being commonly called the "Blossom," occupies the same stratigraphic position as the *O. lugubris* zone, therefore cannot be the Blossom sand, but is Upper Eagle Ford in age. Veatch[2] called these sands the sub-Clarksville sands.

[1] G. C. Matson, "The DeSoto-Red River Oil and Gas Field, Louisiana," *U. S. Geol. Survey Bull. 661* (1917), p. 115.

[2] Veatch, A. C. *U. S. Geol. Survey, Prof. Paper 46*, p. 25.

GEOLOGY OF THE SALT DOMES[1] IN THE CARPATHIAN REGION OF RUMANIA

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University of Cluj, Rumania

ABSTRACT

The Rumanian salt domes are confined to the axial portions of sharp anticlinal folds and fracture zones which affect the sedimentary rocks of the region. The anticlines are aligned with the Carpathian axes. Intrusion of the salt has been accompanied by intrusion of thick masses of breccia composed of sedimentary and some igneous rocks of all ages, including types of rock unknown beneath these portions of the mountains. Both salt and breccia have been thrust upward in diaper manner and even overthrust with sharp, recumbent crests.

The author believes that the salt in the Rumanian domes cannot be of Miocene age, as has been previously contended, and he argues that the original salt beds from which salt domes have formed, not only in Rumania but universally, are products of the evaporation of the earliest lakes and shallow seas to form on the surface of the primitive earth. These waters were rich in chlorides and other salts taken into solution from the heated rocks of the earth's crust and condensed from the heavy blanket of the earth's atmosphere. Part of the immense quantity of salt deposited in this manner was redissolved in the permanent oceans, but after these had become saturated, the main part of the salt deposit remained, to be covered by the first muds laid down on primitive sea floors. They were thus protected until movement and pressure squeezed the salt upward as salt plugs. The intrusion of the Rumanian salt plugs is late Pliocene or early Pleistocene.

INTRODUCTION

Salt is the most widely distributed mineral in the Carpathian region of Rumania, and when all the salt deposits here are known, there will be few countries that can boast the same richness in salt. Already more than 200[2] salt domes and 350 salt springs are known in this region, the springs indicating the presence of deep salt masses. Besides these, some salt or alkaline lakes are found in the projection of the axis of the southern curve of the Carpathian arc (Plate 22).

To facilitate a clear understanding of the occurrence of the salt domes, it is desirable to undertake first a general survey of the geology of the Carpathian region of Rumania.

[1] The translation "salt domes" should now correctly read "salt anticline."

[2] The following salt domes of the Carpathian region are now exploited: two in Maramuresh, one in Bucovina, one in Moldavia, one in Muntenia (Wallachia), one in Oltenia, and five in Transylvania. For the mode of exploitation, see Ing. Zernoveanu, "Sarea si exploatarea ei in Romania" ("Salt and Its Exploitation in Roumania"), *Annales des Mines de Roumanie*, 1923.

GEOLOGICAL STRUCTURE OF THE CARPATHIAN REGION

From a geological point of view, Rumania may be divided into two great regions (Fig. 1):

1. *The Carpathian Mountains proper*, in which all the structural Carpathian zones, folded or not, are included, and form a unit.

2. *Areas adjacent to the Carpathians*, containing the structural units of the forelands, namely: (*a*) the Podolico-Russian platform on the east and northeast border of the Carpathians, the frontal parts of which are found today sunken under the Moldavian upland and the Moldavo-Bessarabian depression; (*b*) the Varisco-Kimmerian chain of northern Dobroudja, on the southeast, which in Permo-Carboniferous time formed a continuous mountain chain with the Sudets; (*c*) the Pro-Balkan platform, on the south containing southern Dobroudja and the Pro-Balkans, the frontal parts of which are found today sunken under the Rumanian plain (the plain of Wallachia) and the Getic depression of Oltenia.

These three outer structural units surround in a semicircle the exterior border of the Carpathian arc, and the tectonic movements in them have contributed strongly to the formation of the structure of the Carpathian Mountains.

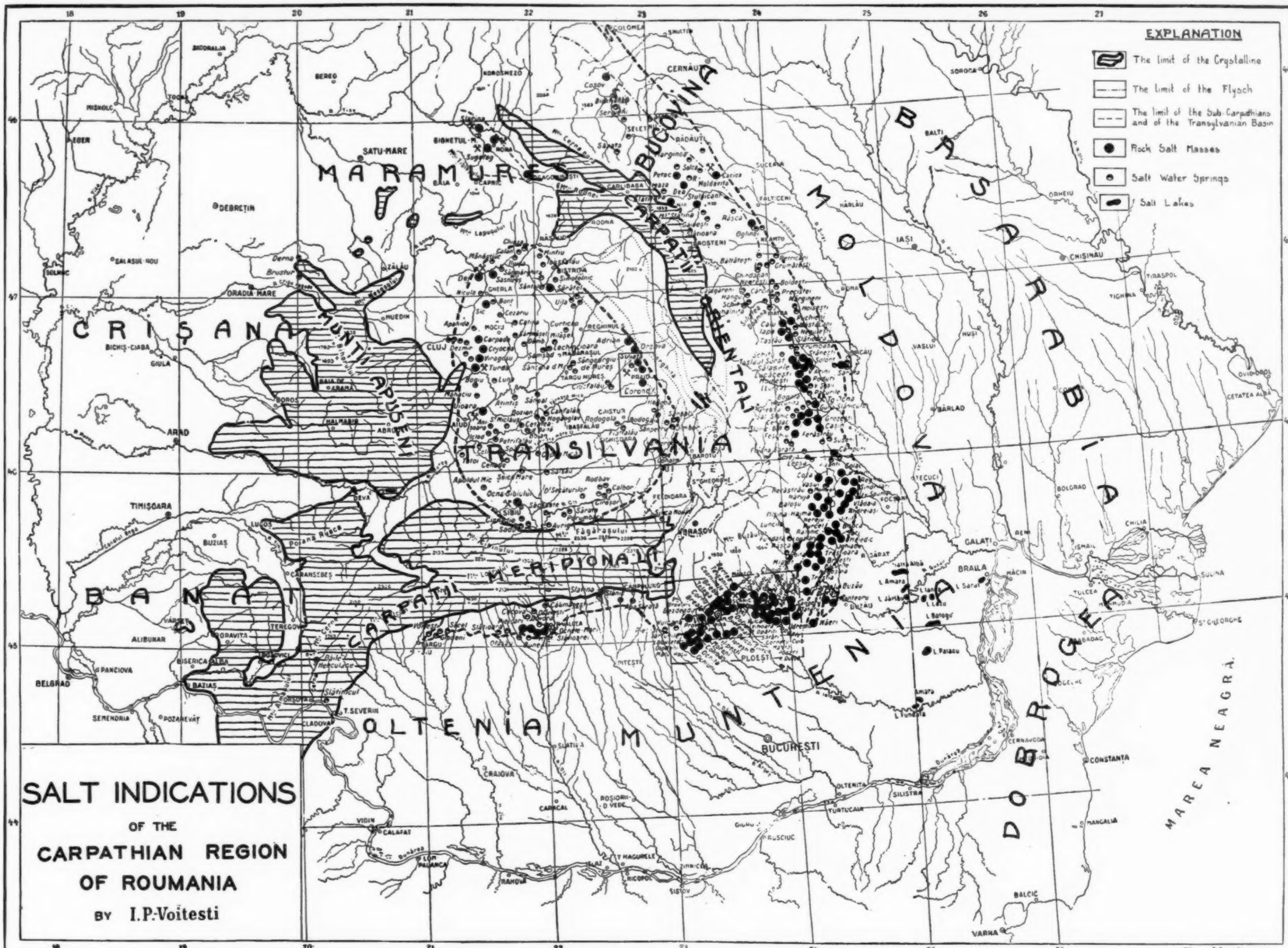
Since the salt-dome masses as well as the saline springs appear only in the Carpathian province, a brief but detailed description of its geological structure will be given.

THE CARPATHIAN MOUNTAINS PROPER

A general morphological study of the Carpathian Mountains reveals the following tectonic units:

a) *The Old Carpathians*, which, on account of their strong development in the old province of Dacia, are designated as the Dacic chains, are formed of crystalline schists, generally Paleozoic, and old granitic rocks; some areas of less metamorphosed Paleozoic formations, Devonian, Carboniferous, and Permian; and Mesozoic formations, Triassic, Jurassic, and Lower Cretaceous—the bathyal facies, preserved in synclinal troughs in the regions of crystalline schists.

The Dacic chains that once with the central zone of the Alps formed a unit—a central Carpathian block—are now isolated sunken



SALT INDICATIONS OF THE CARPATHIAN REGION OF RUMANIA

(The location of detail maps shown in Figures 3, 5, and 7 is indicated)

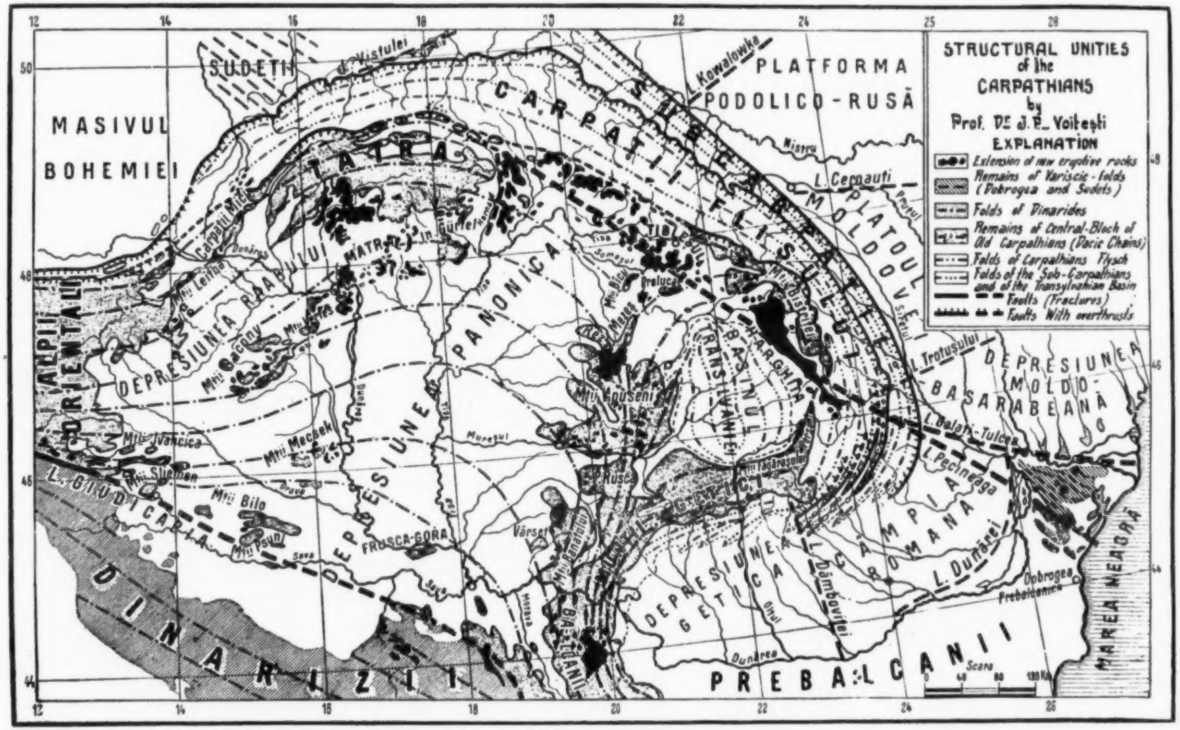

STRUCTURAL UNITIES of the CARPATHIANS
by Prof. Dr. J. P. Voitești
EXPLANATION
Extension of new eruptive rocks
Remains of Variscic-folds (Dobrogea and Sudets)
Folds of Dinarides
Remains of Central-Block of Old Carpathians (Dacic Chains)
Folds of Carpathians Flysch
Folds of the Sub-Carpathians and of the Transylvanian Basin
Faults (Fractures)
Faults With overthrusts
MASIVUL BOHEMIEI
SUDETH
PLATFORMA PODOLICO-RUSĂ
CARPATII FLISULUI
SUBCARPATII
TATRA
PLATOUL MOLDOVEI
DEPRESIUNEA RAABULUI
DEPRESIUNEA PANONICA
BASINUL TRANSILVANIEI
HARGHITA
DEPRESIUNEA MOLDO-BASARABEANĂ
CAMPIA ROMANA
DEPRESIUNEA GETICA
ALPII ORIENTALI
L. GIUDICARIA
DINARIZII
BALCANII
PREBALCANII
MAREA NEAGRĂ
FRUSCA-GORA
L. Kowalowka
L. Cernauti
L. Trotușului
L. Galați-Tulcea
L. Pecineaga
L. Dâmboviței
L. Dunărei
Dobrogea Prebalcanică
Mții Bilo
Mții Mecsek
Mții Bacony
Mții Apuseni
Mții Făgărașului
Mții Bistriței
Dunărea
Mureșul
Oltul
Sava
Drava
Tisa
Prutul
Nistru
Scara
0 40 80 120 Km.

FIG. 1

segments, disposed in two series of descending steps around the great "Panonic depression" that occupies the central part of the block. The steps are separated by smaller secondary depressions: the Raab depression on the west and the Transylvanian basin on the east.

On the Rumanian side of the Panonic depression, that is, on the east, the first more deeply sunken step is represented by "Muntii Apuseni" (the western mountains). The second, separated from the first by the depression of the Transylvanian basin, is composed of two large areas of crystalline rocks. In the southern Carpathians are the crystallines of the Getic Mountains and those of the Banat, which are connected with the southern part of "Muntii Apuseni" by the "Muntii Poiana Rusca"; and in the eastern Carpathians there are the crystallines of the mountains of Bistritza and Maramuresh.

In all these large or small areas of the central block traces of two periods of folding are in evidence: first, the obscured traces of the Hercynian folding (Mid-Carboniferous) over which the conglomerates of the Permian (Verrucano) transgress; and second, the strong folding, with overthrusts of the Middle Cretaceous that gave the present general configuration to the Carpathian chain.

An effect of these movements was the formation of all the large and small structural depressions on the inner and outer border of the central block that separated various chains. Subsequent epochs of folding have only accentuated these features. In the depressions were deposited the post-Lower Cretaceous formations.

b) The Flysch zone of the Carpathians is composed of a broad zone of Cretaceous-Paleogene, deposited in the depression that surrounded the remains of the central block. It was strongly folded in the Oligocene, the Miocene, and at the end of the Pliocene, forming today the high crest of the eastern and northeastern Carpathians.

Toward the southwest the folds in the Flysch, as they approach the great massif of crystallines in the southern Carpathians, pass from the Carpathians to the sub-Carpathians in the form of three anticlinal axes that plunge gradually to the west, squeezed between the great synclinal basins of the Mio-Pliocene that separate them (Fig. 2). These three terminal anticlinal crests correspond tectonically to the three successively superposed overthrusts of the Flysch,

disposed in the form of steps, mounting one over the other toward the exterior, the last one overriding the sub-Carpathians. These, in turn,

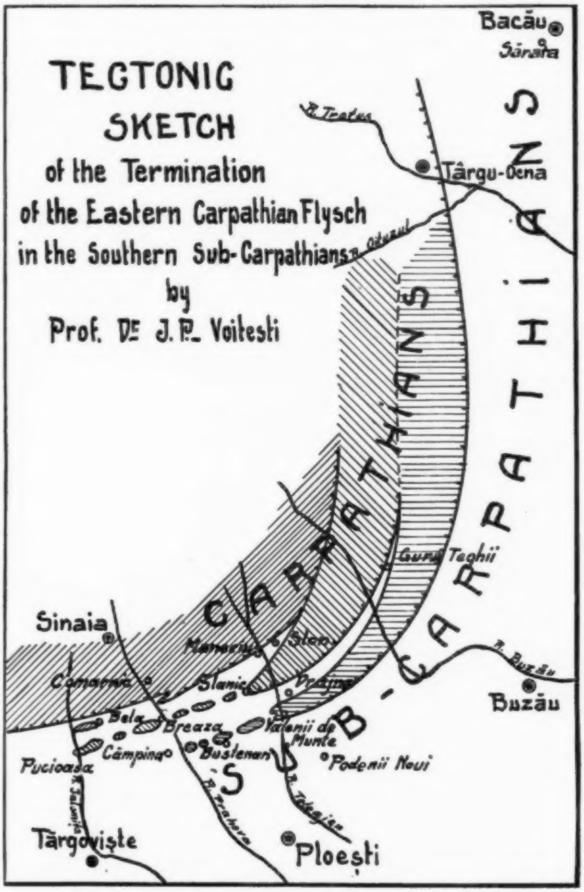


FIG. 2

correspond to the three facies of the Eocene (the interior facies, the facies of Fuzaru sandstone, and the marginal facies) of the eastern and northeastern Carpathians.

c) *The sub-Carpathians,* consisting only of Tertiary sediments, represent the newest system of folds that were added to the Carpathian Flysch at the end of the Pliocene or beginning of the Quaternary, and that surround it completely.

These three great tectonic units of the Carpathian region represent, thus, three zones that were folded at different epochs, the newer being added successively on the exterior of the older.

At the same time each of these tectonic units represents one complete evolutionary cycle (lithogenesis, orogenesis, glytogenesis) of the stages through which the geosyncline of the Carpathians has passed. The geosyncline has been moved outward three times under the influence of the successive sinkings, in the form of steps, of the frontal regions of the forelands.

These outward displacements of the Carpathian geosyncline at different tectonic periods have caused the three tectonic units of the Carpathians (the Dacic chains of the old Carpathians, the Flysch zone of the Carpathians, and the sub-Carpathians) to be disposed in three steps descending outward, separated by lines of strong longitudinal fractures, along which the older and inner overlap the newer and outer ones.

SALT DOMES AND SALINE SPRINGS

RELATIONSHIP OF SALT DOMES TO THE STRUCTURAL ZONES OF THE CARPATHIANS

Very few springs (Plate 22) are connected with the step blocks of the forelands, and these, like the salt springs of the Moldavian upland and those that supply the salt and alkaline water lakes of the Rumanian plain adjoining the southern curve of the Carpathians, contain only a small amount of NaCl, though more $NaSO_4$ and $MgSO_4$. The salt domes, as well as the pure salt springs, appear only in the Carpathian region proper.

Aside from the saline and sulphurous hot springs which appear in the fractures bordering the granite of the valley of Cerna at the Baths of Hercules (Banat) and which are surely connected with the post-volcanic manifestations of this region, it is found that masses of rock salt or saline waters occur in almost all the formations underlying the Carpathian regions.

Beginning with the oldest formations, a strong salt spring is found in a fracture of the crystalline mica schists in the mountains of Persani, at Sinca Noua, in the southeastern part of Transylvania.

In the Lower Cretaceous (Albian), salt springs occur at Comarnic, Bertea, and Vulpea, in the district of Prahova; and at Bela, in the district of Dambovita, in the western prolongation of the anticline whose core contains the salt mass of Bezdeadu (Plate 22 and Figs. 3 and 4).

Under the sandstone of the Upper Cretaceous (Cenomanian), a salt mass and two salt springs appear under the peak of Maciucu Bertei (Bertea, Prahova).

In the Paleogene of the Carpathians (Eocene and Oligocene), there are innumerable salt springs and a great many salt domes extending the entire length of the Flysch zone from north of Bucovina to west of the Olt, in the southern sub-Carpathians, and from its exterior to its interior border. The salt masses occur always in the more or less fractured anticlinal crests. In the Flysch of the eastern Carpathians, the salt masses as well as the salt springs are much more numerous in the vicinity of its outer border fault (Plate 22 and Figs. 5 and 6). In the prolongation of this zone in the southern sub-Carpathians the occurrences of salt masses and salt springs are closely connected with the terminal anticlinal crests of the Paleogene that disappear gradually toward the west.

In the Miocene, Pliocene, and even Quarternary, there are many salt domes and springs along the entire length of the eastern sub-Carpathians, from northern Bucovina to their southern curve, and from there westward throughout the southern sub-Carpathians, as far as the valley of Jiu. They are most numerous in the neighborhood of the marginal fracture of the Flysch and of the flexure along the outer border of the sub-Carpathians (Plate 22). Salt domes and springs are also found in the Miocene and Pliocene of the interior of the Carpathian chain, in the Transylvanian basin, where the greatest number of the salt domes seem to be connected with the marginal fractures of the depression, although there are some within the basin, as well as in the Maramuresh (Plate 22 and Fig. 7).

Salt is found even in the great Panonic depression, for at Brustur (Tartaros), on the northwest border of the crystallines of the eastern

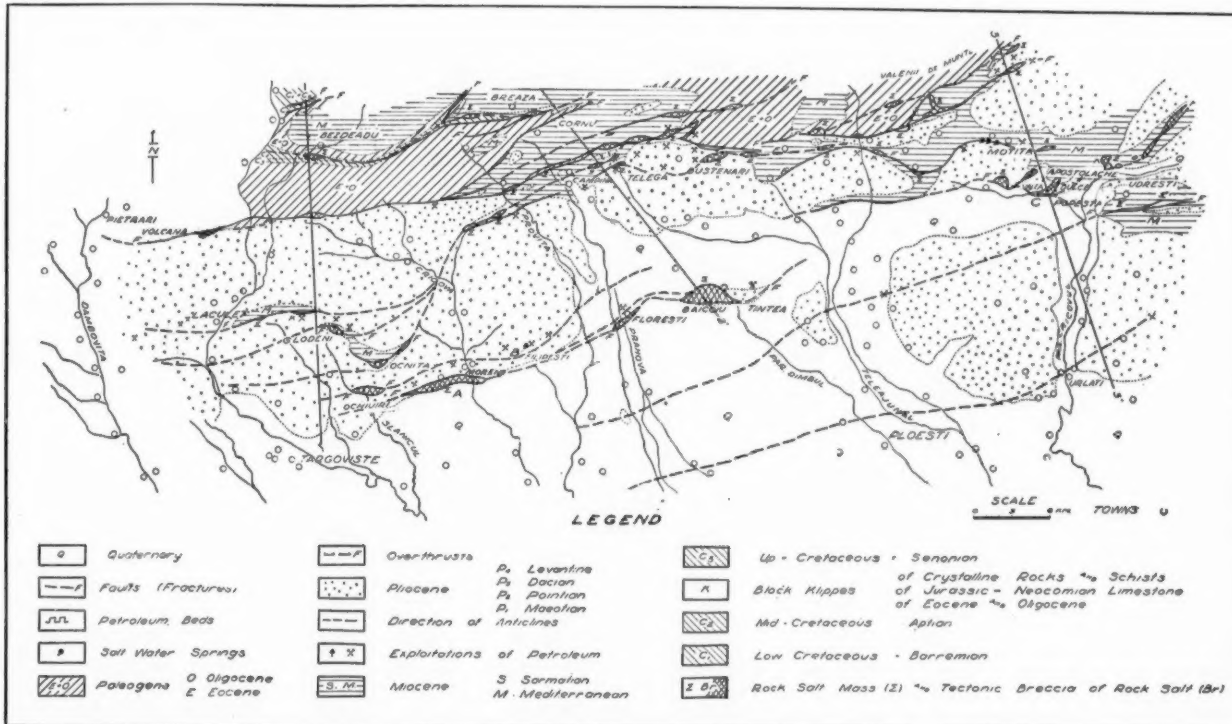


FIG. 3.—Geologic map of the south side of the southern Sub-Carpathians, with special regard to the distribution of the rock salt domes

(For location see Plate 22)

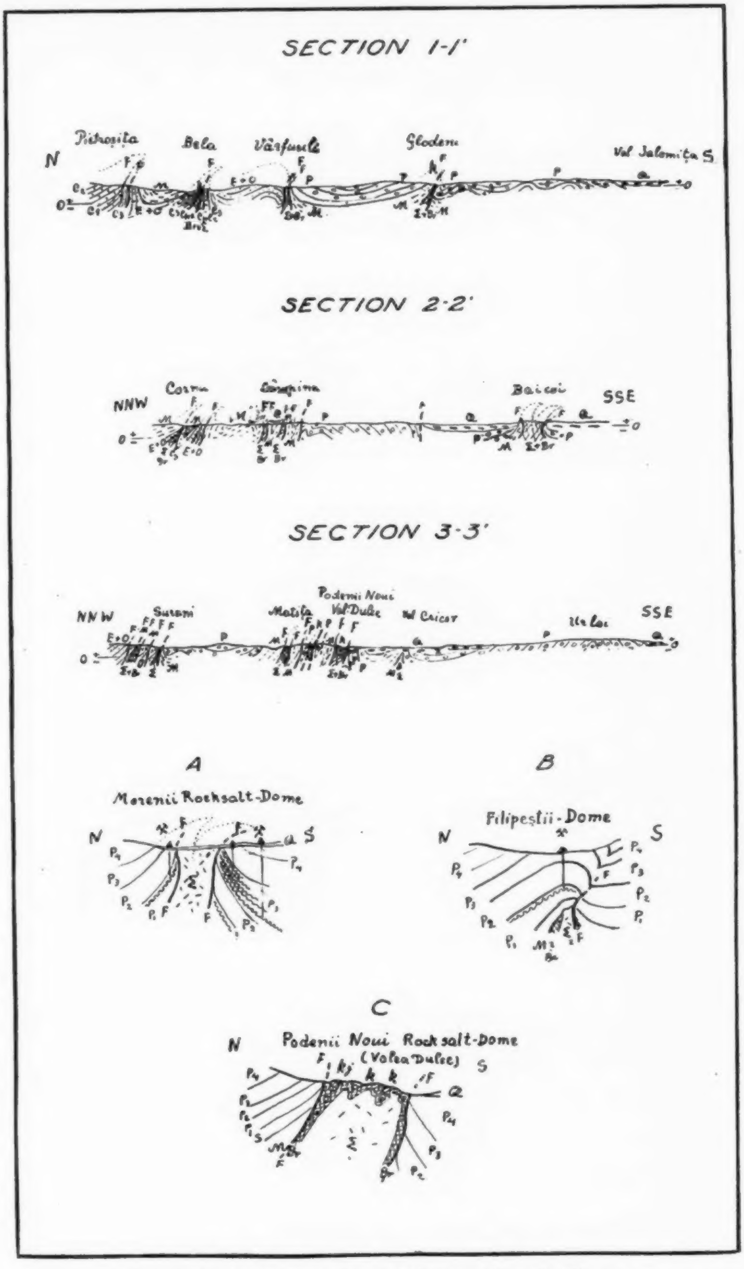


Fig. 4.—Geologic cross-sections of the area shown in Figure 3

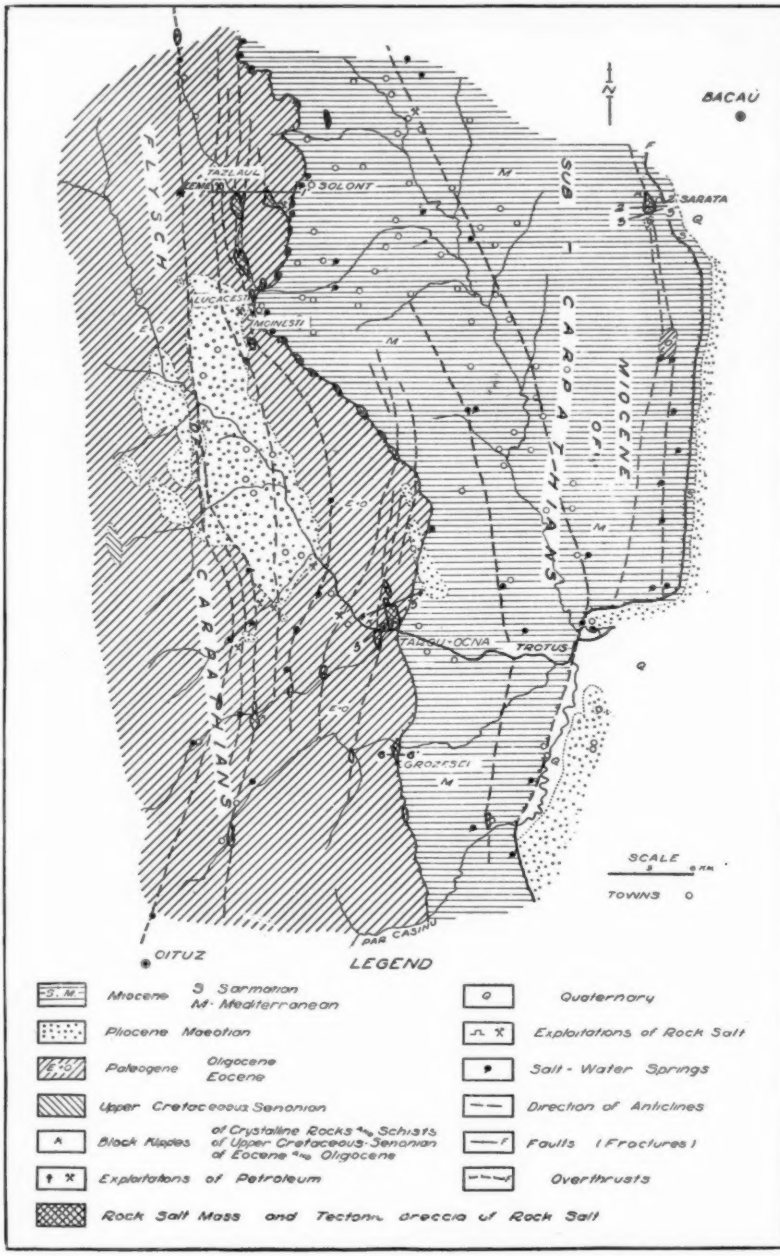


FIG. 5.—Geologic map of the east side of the eastern Carpathians and Sub-Carpathians, with special regard to the distribution of the rock salt domes. For location see Plate 22.

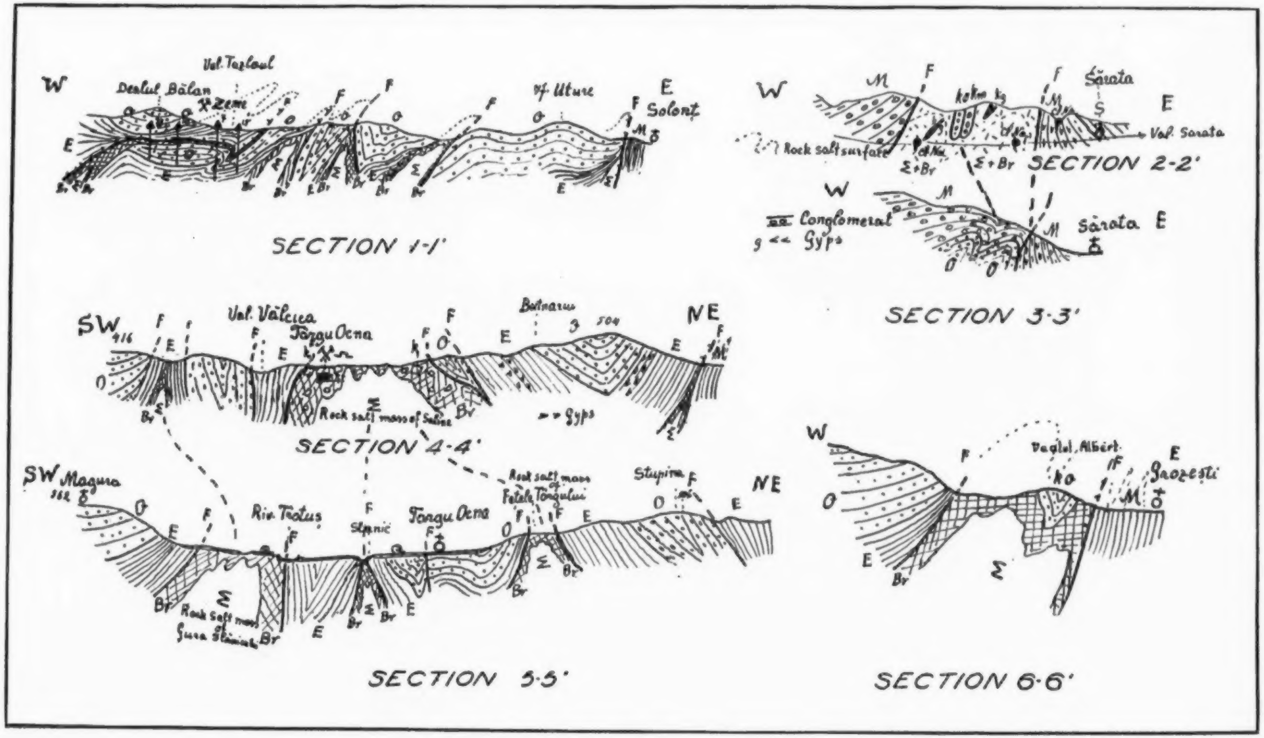


FIG. 6.—Geologic cross-sections of the area shown in Figure 5

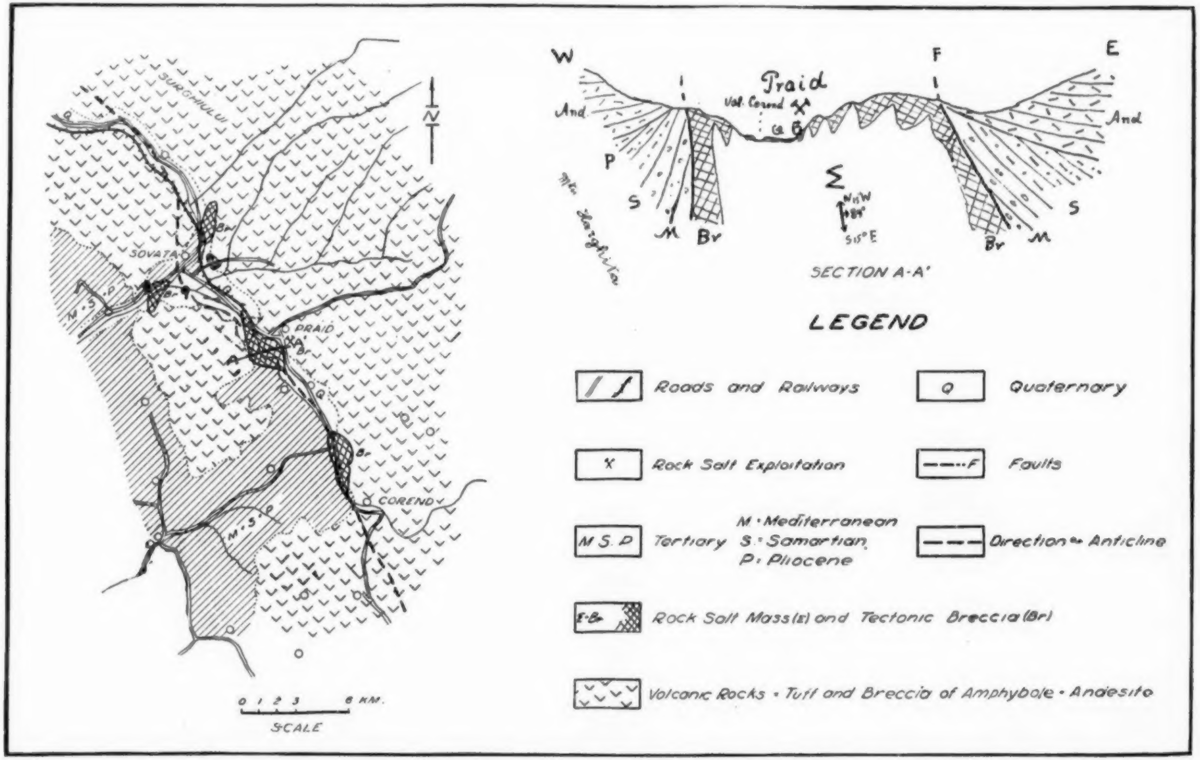


FIG. 7.—Geologic map of the eastern border of the Transylvanian basin, with special regard to the distribution of rock salt domes

(For location see Plate 22)

mountains ("Muntii Apuseni"), on the fault that separates these crystallines from the Mio-Pliocene of the depression, there is a strong salt spring.

The map of the salt deposits and salt spring (Plate 22) shows that in Bucovina they are scattered over the whole zone of the Paleogene Flysch, from the border of the crystallines to the sub-Carpathians, while in Moldavia they are commonly grouped together near the outer border of the zone of Paleogene Flysch and the inner border of the Miocene of the eastern sub-Carpathians.

The southern curve of the Carpathians may be considered as beginning at the river Trotus and the town of Targu-Ocna, where the strike is N. 15°–20° E., continuing to Ochiuri-Ocnita, in the district of Dambovita, where the strata strike is N. 70°–75° E. Outside the Carpathians the salt masses as well as the salt springs are not only more numerous, but also scattered over the entire breadth of the sub-Carpathians, from their border toward the plain, beyond the inner border of the terminations of the Paleogene Flysch, up to the fractured border of the Lower Cretaceous zone of the high Carpathians. In the vicinity of the same curve, and especially in the southern part of Moldavia, the salt domes and springs appear in the interior of the Paleogene Flysch zone of the Carpathians up to the high crest of the mountains. They are found in the valley of Slanicul Moldovei, and in the valley of Oituz, even beyond this crest (at Poiana Sarata and Oituz), on the Transylvanian side of the mountains (Plate 22 and Figs. 5 and 6).

It should be remembered, also, that opposite this curve of the Carpathians there are the salt and alkaline lakes of the Rumanian plain, scattered over the whole zone between the rivers Ramnicul Sarat, Ialomita, and Danube (at Braila), the lakes being supplied by springs containing salt and magnesia.

In the Transylvanian basin the salt domes appear along the anticlinal crests in the direction of the Miocene (north-northwest—south-southeast), the salt masses being much more numerous along the fractures that accompany the borders of this depression than in the interior of it. In Oltenia these occurrences are all grouped together in the narrow strip of Cretaceous-Paleogene-Miocene, in the vicinity of the fault of the crystalline outlier of the Getic Mountains.

In Maramuresh they are grouped in the Paleogene-Miocene in the northeastern end of the Panonic depression, which touches here on the border of the crystallines of the northeastern Carpathians.

The broad zones separating the salt domes and springs in the interior of the old Carpathians from those on the exterior generally have a foundation formed of crystalline schists, deeply metamorphosed, and old eruptive rocks as well as the spots of Paleozoic-Mesozoic, more or less metamorphosed and closely connected tectonically with the crystallines.

From these statements it might be deduced that the salt domes of the Carpathian regions are connected with the zones in which the older geologic formations have not suffered such metamorphism. Also, study of the grouping of these salt domes in the different structural units of the Carpathian zones show that they are connected with the zones of more recent geosynclinal depression, namely, of the geosynclines produced since the Upper Cretaceous. The occurrences of salt masses and springs are much more numerous as these increase in proportion to the depth of the troughs.

RELATIONS OF THE SALT DOMES TO THE FOLDS AND FRACTURE LINES OF THE CARPATHIAN MOUNTAINS

All the salt masses and springs of the Carpathians are confined to the cores of the anticlines, regardless of the age of the geologic formations constituting their flanks or their cores. In no case do these domes or springs appear in synclines. Where the salt masses come to the surface in the cores of the anticlines, their crests are fractured, and very frequently, besides these fractures, the flank that is on the inner side of the corresponding Carpathian zone overlaps the outer one, which, in this case, is sunken and folded over the adjoining syncline (Figs. 3 and 4). In the sub-Carpathians as well as in the Transylvanian basin, but especially in the zone of the Cretaceous-Paleogene Flysch of the eastern Carpathians and the southern sub-Carpathians, the anticlinal lines are in most cases highly developed in the whole region. The salt masses are aligned along them in garlands piercing their crests from place to place. In the points where the salt masses did not reach the surface, salt springs are found on the apex of the anticlines (Figs. 3, 4, and 5). The great development

of longitudinal faults throughout the Carpathians has facilitated the intrusion of the salt. This is the case with the great longitudinal fault on the outer border of the Flysch of the eastern Carpathians where the Cretaceous-Paleogene Flysch overlaps the sub-Carpathians and where the most numerous salt domes appear. The same is true in the fractured anticlines in which the Cretaceous-Paleogene Flysch of the eastern Carpathians ends in the southern sub-Carpathians. Other examples are the great flexure on the outer border of the eastern and northeastern sub-Carpathians, and those on the ends of the anticlines of the Mio-Pliocene in the southern sub-Carpathians toward the Rumanian plain and the Getic depression of Oltenia (Figs. 3–6). Finally, faults also delimit the depression of the Transylvanian basin (Fig. 7), which contains many salt domes.

TECTONICS OF SALT-DOME INTRUSION

Irrespective of the zone in which they appear, whether the Carpathians, sub-Carpathians, the Transylvanian basin, or the prolongation of the Panonic depression in Maramuresh, the salt masses appear to be genetically identical. The salt everywhere appears in the form of great lenticular masses more or less elongated along the major anticlinal axes and generally cutting the anticline obliquely in vertical section.

Around the salt mass there is generally a tectonic breccia, formed from fragments of different rocks, whose size varies from fine clay up to large blocks, rounded or angular with dimensions from some centimeters up to several meters, and sometimes (in Valea Dulce, at Podenii Noi) even some hundreds of meters (Figs. 3 and 4). The formations that remain unbrecciated on the flanks of the anticline sometimes present incipient stages of brecciation. In the great majority of cases these strata have been thrust backward and upward. Their margins are thinned upward along the gliding surface that separates them either directly from the salt mass, or from its surrounding breccia, when this is present. Each component of the domes will now be described.

The salt.—The salt is chemically very pure and is all crystalline, generally with a granular structure, and rather fine-grained. Only in the sheared zones with brecciation and recrystallization does the salt

appear impure, harder, and in large cubic crystals, which are sometimes very large. Foreign elements are gypsum and fragments of clay folded into the salt.

The salt masses are always banded with darker stripes because the salt is a stratified deposit. The thick strata are white; the thin strata (2–3 cm. thick) are dark in color but pure in composition, the darker coloration being due possibly to some inclusions of a

FIG. 8.—Variegations and phenomena of dissolution on the surface of the rock salt outcrop at "Baia Baciului," Slănic, Prahova (Muntenia).

chemical nature[1] (Fig. 8). The presence of these bands furnishes a means of knowing the intimate tectonic structure of the mass. The countless synclinal and anticlinal folds (Fig. 9) which show intense squeezing and fracturing, especially in the synclines, indicate the powerful compression that the salt masses underwent during their intrusion. The abundant breccia that is developed around the salt masses is obvious proof of the enormous mechanical force that was

[1] Dark color bands in American salt domes are caused by anhydrite crystals.—EDITOR.

exerted against the rocks of the cores and the arches of the anticlines in order to pierce them on their way upward. This force caused the characteristic folded structure.

The flanks of the domes are usually curved and almost vertical. Downward enlargement is asymmetrical with the straight side away from the direction of thrust. The crest of the salt mass or the crests, if these are multiple (Baicoi-Tintea, Bana, Cacica, etc.), present

FIG. 9.—Anticlinal fold made conspicuous through variegations in a gallery in the "Ocnele Mari," Valcea (Oltenia) salt dome.

different aspects according both to the section of the mass considered and to the shape of the anticlinal fold.

Domes that reached the surface through a complete fracturing of the anticlinal crest crop out in circular form. Where the anticline contains local domal nodes, as is generally the case of the salt masses of Transylvania (Uioara, Sovata, Praid, etc.), the salt core enlarges downward a short distance. The outline of other salt cores is oval (Gura Slanicului, Moldova, Ocnita, etc.). Still others have sinuous, pod-shaped, or crescentic outlines, as in the domes of the Carpathians or the sub-Carpathians (Targu-Ocna, Moreni, Ochiuri, Slanic-

Prahova, Ocnele Mari-Valcea, Martiia, Apostolache, Podenii Noi, etc.). These are on long anticlinal lines whose crests are more or less inclined and sometimes recumbent (Figs. 3–7).

Outcrops of salt show characteristic signs of erosion modeled by running water (Figs. 8, 10, and 11). They show concave surfaces, large funnel-shaped sink holes, and salt lakes (Telega, Targu-Ocna, Gura Slanicului, Sovata, Slanic, etc.). Sometimes, because the bot-

FIG. 10.—View of the rock salt mass of Slănic, Prahova that appears at "Baia Baciului." A recumbent anticlinal fold is to be observed.

tom is covered with fine deposits of clay, the lakes contain fresh water (Baicoi, Campina, etc.).

Surficial enlargement of the edges of the salt cores, as determined by vertical sections, is due to the plasticity of the salt, which causes flowage on release from the pressure of the rocks on the flanks of the anticline. Salt cores that do not reach the surface have a lenticular form, with a sharp crest, or are irregularly folded. The crests of some domes after having pierced vertically a part of the rocks curve laterally and intrude horizontally between the upper strata for greater or less distances (Dej, Transylvania). Considered as a

whole, the salt core constitutes an entire and compact unit, like a great lenticular kernel, intensely folded and refolded.

There are cases in which the salt core has two peaks, separated by a strongly compressed syncline of sedimentary rocks (Baicoi-Tintea). This syncline is sometimes completely brecciated (Cacica-Bucovina), the two peaks being in this case separated by a large zone of breccia. In other cases, through squeezing and flowage, the breccia

FIG. 11.—The rock salt mass of Praid, Transylvania, crossed by the valley "Corond"; the salt is white, the tectonic breccia dark.

has been completely obliterated, the peaks being separated by only a thin zone of a harder salt, with larger and less pure crystals, containing rock inclusions that are more numerous at the edges of the core (Slanic-Prahova, Ocnele Mari-Valcea, etc.).

All the fossil remains found thus far in the rock salt come only from those inclusions which were torn off in the synclinal parts of the intrusion and afterward squeezed and laminated. Consequently, they do not belong to the salt, but to the sedimentary formations surrounding it, through which the salt mass has penetrated. The breccia separating the crests of the salt mass of Cacia (Bucovina) con-

sists only of Oligocene and Eocene rocks. The very laminated breccia in the salt mass of Slanic-Prahova is formed of Eocene and Mediterranean rocks. The rocks separating the crests of the Baicoi-Tintea and Bana (Prahova) salt domes belong to the Upper Pliocene (Docian).

The Breccia around the salt cores.—This breccia is a tectonic formation, and was produced during the intrusion of the salt mass by the fracturing of all the formations through which it pierced. The greater part of the breccia is derived from the rocks of the uppermost formations. Around the salt cores of the Cretaceous-Paleogene Flysch of the eastern Carpathians the breccia contains fragments of the Senonian, Eocene, and Oligocene. Eocene-Oligocene fragments predominate in the cores that pierced to the surface through the whole series of Flysch (Targu-Ocna, Stanesti-Solont, Grozesti, etc.). Fragments of Eocene rocks only occur in the masses that did not pierce through the whole series (Gura Slanicului, Slanic Sat, Tazlaul Sarat, etc.).

In the sub-Carpathians, where the known geological formations embrace the entire Tertiary, the breccia usually consists of Paleogene-Miocene rocks. One example is Sarata, near Bacau, where there also is a great *Klippe* of Paleogene; others are found in the southern sub-Carpathians (Slanic-Prahova, Gorganu, Valea Bisericii at Poiana de Variblau, etc.), in the region of the last anticlines in which Paleogene Flysch is exposed, Figs. 3–6).

Around the cores that have stopped in the Miocene of the Transylvanian basin, as well as around those on the outer border of the southern sub-Carpathians and in the Getic depression, the tectonic breccia consists either of Miocene rocks only (Transylvania and the Getic depression) or of Miocene and Pliocene rocks. A number of *Klippen* of Oligocene occur on the border toward the plain of the southern sub-Carpathians (Floresti, Matita, Apostolache, etc.), and on the eastern border of the Transylvanian basin (Sovata, Corond, etc.).

In most of the domes in the Pliocene of the southern sub-Carpathians, either breccia is absent (Ochiuri, Gura Ocnitei-Moreni-Bana, etc.), in which case it was left behind when the salt mass entered the Pliocene, or the breccia is represented only by some rather

small masses that could have been broken off and carried up by the salt mass from the breccia that remained at a depth (Baicoi-Tintea, Floresti, etc.). The scarcity of breccia is attributed to the plasticity of Pliocene rocks, which consist of loosely compacted sands and clays.

Fragments of formations older than the Tertiary in the southern sub-Carpathians are confined to the breccia around the salt masses in the vicinity of the marginal fault of the southern Carpathians and in the zone of the terminal anticlines of the Carpathian Flysch, ending in the sub-Carpathians. Thus, at Bertea (Prahova) the salt springs issue from the Aptian, which is brecciated by a salt dome[1] that did not reach the surface. In the valley of Saratila, at Breaza (Prahova), the breccia contains Paleogene-Miocene as well as Senonian rocks. In the core of the anticline of Bela-Bezdeadu (Dambovita), in which a salt core occurs, rocks belonging to the Aptian, Senonian, Eocene, Oligocene, and Miocene appear in the breccia and on the flank of the anticline. Some enormous blocks of Jurassic limestone have been found in some cases, as at the Vf. Ursului (Figs. 3 and 4).

Considered from the point of view of the resistance of the rocks from which the breccia was formed, the marls and shales are generally finely ground, the conglomerates are completely disassembled by breakage, and the sandstones and limestones are generally broken to pieces, their fragments large or small usually being angular. The rounded pieces of quartz in the conglomerates, through rubbing with finer fragments, are sometimes perfectly polished. Some geologists confuse this polish with the gloss of desert varnish.

Besides these constituents, whose origin may be very easily determined by comparison with the rocks of the surrounding formations, fragments of unknown formations that are wholly foreign to the region and cannot be attributed to any of its known geological formations are found.

In the tectonic breccia of all the salt masses that appear in the Carpathian Flysch and in the Miocene of the eastern sub-Carpathians, besides large or small fragments of eruptive rocks and

[1] "The salt itself is not responsible for the brecciation. It is due to structural forces, which also squeezed the salt upward."—Bloesch.

crystalline schists that may be compared with those in the distant areas of crystalline in the old Carpathians, there are also found numerous fragments, generally angular, usually small but in places enormous, of eruptive rocks and green crystalline schists, of the types that form the remnants of the old Variscian chains of the northern Dobrodja. These fragments can be derived only from the old Variscian foundation of the geosyncline of the Carpathian Flysch and of the eastern sub-Carpathians, a basement formed by the prolongation of the northern Dobrodja chains which sank during the formation of this geosyncline (Poiana Sarata, Grozesti, Slanic Sat, Targu-Ocna, Tazlaul Sarat, Sarata-Bacau, etc.).

In the same manner in the southern sub-Carpathians, besides the fragments that came from the surrounding formations (Cretaceous, Paleogene, Miocene) and formations older but still of the Carpathian type, as fragments of crystalline schists and eruptive granitic rocks of the Carpathian type and Mesozoic (Jurassic) limestones closely connected with this crystalline in the southern Carpathians, there also appear in the salt-dome breccia a few fragments of rocks wholly foreign to the Carpathian region. Their proportion in the breccia is proportionally greater, the nearer the salt mass is to the plain. For instance, in the salt-dome breccia of Valea Dulce, near Podenii noui (Prahova), besides the large and small angular fragments of mica schist and (eruptive) gneiss of Cozia, and Jurassic fossiliferous limestone of pure Carpathian type, there also appear exotic fragments of a black quartzose sandstone (Carboniferous?), a red porphyry with great crystals of feldspar, and blocks of limestone with *Nerinea*, one of which, now completely exploited, was over 700 cubic meters in size. These rocks are generally known only in the Dobrodja and the Pro-Balkans, not in the Carpathians, and they were surely derived from the Pro-Balkan foundations of the Rumanian plain and of the southern sub-Carpathians (Figs. 3 and 4).

All these fragments of the breccia form a strongly compacted mass, well cemented by the salt,[1] sometimes also by gypsum. Generally the salt of the cement becomes much more abundant in the vicinity of the salt mass, where the breccia is finer and is more

[1] At Targu Ocna, in the rock-salt dome, breccia of *Valea Larga* were found, also some blocks of potassic salt (carnallite and sylvinite).

strongly compressed than toward its exterior. Gypsum very often re-cements the sandstones and the broken conglomerates; in places it even forms lenses of fibrous gypsum or kidney-shaped crystalline masses.

Where the breccia appears at the surface it may be very easily recognized from distinctive characteristics: salt springs or strong

FIG. 12.—Knotty clay-breccia in contact with the surface of the rock salt mass of Sovata, Transylvania.

saline efflorescences; the greasy aspect and knotty texture of the soil (Fig. 12); the presence of fragments of several kinds of more resistant rocks heaped up on the surface; the finer materials of the breccia having been washed away by the rains; and, finally, the complete lack of vegetation, or, if any exists, the presence of plants which grow on salty soils.

The rocks in the flanks and on the anticlinal arches that remain unbrecciated by the salt cores.—The visible formations constituting the

flanks and the crests of the anticlines which are intruded by the salt masses belong generally to the Pliocene, Miocene, and Paleogene, less frequently to the Upper and Lower Cretaceous. The formations vary according to the region in which the salt domes appear.

When the anticlinal arch is completely brecciated, the trace of the outcrop of strata that remain unbrecciated is lens-shaped. The dips are different on either flank, being less steep on the upper flank and greater on the inverted one. In the neighborhood of the breccia, or, when this is missing, near the salt mass, the strata on both sides are turned upward, squeezed, and reduced in thickness through lamination. Near the surface where the salt overflows they are bent outward, forming fan-shaped anticlines. These overturnings are much more pronounced on the inverted flank, which is generally depressed and hence often overlapped (Figs. 3–7).

Owing to the numerous wells in search of oil that have been drilled in the vicinity of the salt domes—the formations of the petroleum deposits in Rumania having close genetic connections with the salt domes—it has been established that the salt is diffused in the strata of the flanks of the anticlines for great distances around the salt mass when the fractured borders of these strata come in direct contact with the salt mass or its breccia. This is shown chiefly through the presence of salt water in the porous rocks of the flanks.

Toward the extremities of the salt lens, where the salt core disappears, the strata of the two flanks unite to form the arch of the anticline. Here the overlying strata are curved in the form of a broad arch and those of the core are folded together like a sharp wedge with the edge upward. The underlying strata are more or less thinned through squeezing and lamination (the "diapir" folds of Mrazec). According to the position of this wedge, whether vertical or oblique, these are classed by Mrazec as upright, oblique, or recumbent diapirs (with a piercing core). The last two in most cases are fractured and overturned.

An essential characteristic of these diapir folds is that, from a geographical point of view, the strata of the anticlinal arch are generally passive, the core alone being active in causing the intrusion. This may be seen in the study of the arches that were not completely pierced. The arch takes the form of an elongated dome, with the

core more or less brecciated. In this case the extremities of the dome present the same structure as in the case of complete piercing. But the dome, judged from the point of view of symmetry, may present two different cases. The first is when the salt mass rose vertically (and in this case the arch is symmetrical), but the strata of the flanks are laminated through squeezing, until they are completely torn from those of the arch. This is the case in the anticlines of Ceptura and Arbanas, in the southern sub-Carpathians. The second case is when the salt mass does not rise on a vertical line, but obliquely, and then the arch and the flanks are naturally asymmetrical, the inverted one being more inclined, distended, and sometimes drawn out to complete rupture. Examples are known at Filipestii de Padure and generally in the whole Transylvanian basin (Figs. 3–7).

AGE OF THE SALT OF THE CARPATHIANS

The first person who tried to establish the age of the rock salt of the Carpathian deposits was the Viennese scholar, the geologist Eduard Suess (1).[1] He correlated it with the *Schlier* (the base of the second Mediterranean—the base of the Helvetian) of the Miocenic outer Alpinic basin of Vienna. The great authority of Suess caused this age to be accepted without much discussion by all the geologists of the countries bordering the Carpathians—Rumanians, Austrians, Polanders, and Hungarians.

Later on, after the discovery of some Tortonian fossils in the breccia of the salt dome at Wieliczka and at Bochnia (2, 3, 4), the Galician geologists, and, after them, Haug (5), considered the salt of the sub-Carpathians as representing a lagunal facies of the Tortonian.

The Hungarian geologists, Posepny, but chiefly Koch (6) and H. Böckh (7, 8), who occupied themselves more intimately with the stratigraphy of the Transylvanian basin, considered the salt as intercalated in the marls that form the base of the bathyal facies of the Helvetian (the strata of Mezoseg), marls resting directly on the lower and thicker beds of eruptive tuff (Dacitic).

Further studies on the Mediterranean of the sub-Carpathians gave rise to numerous discussions among the Rumanian geologists

[1] The numbers here and elsewhere refer to the bibliography at the end.

about the age of the rock-salt masses. Mrazec and Teisseyre (9, 10, 11) originally assumed an Eocene-Oligocene age for the salt of the Carpathians, and a Mediterranean (Helvetian) age for the salt of the sub-Carpathians. Later on, Mrazec (15) and Voitesti (16) brought it down to the base of the first Mediterranean (Burdigalian), and, although this opinion was contended (Sava Athanasiu [13]), the majority of the Rumanian geologists (Murgoci [12], Macovei [14], Merutiu [17], etc.) accept the same age today.

The author (18–24) of this paper, from 1911 to the present, has drawn the attention of geologists several times to the mistake that is being made in considering the salt as Miocene. Excluding the great number of salt masses appearing in the interior of the Carpathians, at enormous distances from their outer border, where the Cretaceous-Paleogene Flysch of the Carpathians comes into contact with the Miocene, the salt masses that appear in the Miocene and the Pliocene of the sub-Carpathians pierce not only through the whole series of Mediterranean and Pliocene strata, but even extend through the Eocene and Oligocene formations which always appear as large or small *Klippe* (overthrust) areas, generally brought up from a depth by the rock-salt masses. Thus, the mass of Sarata, near Bacau, on the exterior border of the Miocene of the eastern sub-Carpathians (Figs. 5 and 6), appears beneath a large *Klippe* of Oligocene, which, together with the whole overlying series of Mediterranean strata, is completely brecciated, in the zone where the salt mass is present (Voitesti [19]). With a marginal position in the sub-Carpathians the salt masses between Vizantea and Soveja (district of Putna) also appear beneath the great *Klippe*[1] of Paleogene of the peak Rachitasul. In the southern sub-Carpathians the most numerous salt masses are in the zone of the *Klippen* of Eocene and Oligocene that are the western extension of the anticlines of the Flysch.

Klippen of Paleogene rocks are not confined to this terminal anticlinal zone. They also occur on the Mio-Pliocenic border, toward the plain of the sub-Carpathians, for instance, in the salt domes of Scaiosi, Opariti, Sarari, Matita, Apostolache, Udresti (25), Gura Draganesei, etc. Moreover, all the salt domes that appear along the

[1] *Klippen* are outliers of an overthrust (Chief Mountain Montana, is an example) in contrast with a *Nappe* (*Decke*) which is the overthrust mass itself.—EDITOR.

fracture zone of the exterior border of the eastern Carpathians (along which zone the Cretaceous-Paleogene Flysch overlaps the Mediterranean of the sub-Carpathians) have a tectonic breccia formed exclusively of fragments of Eocene-Oligocene rocks (Cacica, Lucacesti, Moinesti, Targu-Ocna, etc.), or else largely of Eocene-Oligocene rocks with very few fragments of Mediterranean rocks in the

FIG. 13.—The tectonic breccia of the "Fetele Targului" salt plug, near Târgu-Ocna, Moldova, formed of Eocene and Oligocene rocks with inclusions of Cretaceous limestone and of crystalline schists. Note the funnel-shaped aspect of its surface.

upper part of the breccia (Calu, Stanesti, Valea cu Arini, Poduri, Grozesti, etc. [Plate 22; Figs. 5, 6, and 13]). Furthermore, along this marginal fault there are numerous cases in which we find the salt masses hidden partly under the border of the Paleogene Flysch; partly under the rocks of the neighboring Mediterranean, as, for instance, in the border region of the Flysch, between Targu-Ocna and Solont (district of Bacau [see Figs. 5 and 6]), and in the region of the southern curve of the Carpathians (in the district of Ramnicul Sarat), in which regions the folds of the Flysch are cut off obliquely by this marginal fault.

If to these examples the salt domes of Bertea-Vulpea, Breaza, and Bezdeadu-Bela, in the anticlinal flanks and tectonic breccia of which the Cretaceous (Senonian and Aptian) formations as well as the Paleogene occur, are added, and if the fact is remembered that wherever the salt masses appear they present the same tectonic and physico-chemical conditions, the conclusion is logical that the rock-salt masses of the Rumanian Carpathians and sub-Carpathians cannot, in any case, be considered Miocenic—a conclusion also reached by some foreign geologists who studied conditions in the field (E. H. Cunningham Craig [26]).

The salt domes of Transylvania, which have been studied by the author (Ocna Sibiului, Uioara, Turda, Cojocna, Dej, Sovata, Praid, and Corond), show absolutely identical tectonic and physico-chemical conditions. There surrounding breccia, sometimes enormously developed (Turda, Sovata, Praid, Corond), is formed only of fragments of rocks of the Mediterranean, in which the salt mass is arrested, and fragments of crystalline schists and old eruptive rocks (Turda, Sovata) sometimes very strongly represented (Praid, Conond). All these fragments may come from the conglomerates at the base of the Mediterranean. Up to the present, fragments have not been found in these breccias that can be assigned with absolute certainty to formations older than the Mediterranean. One fact, however, remains well established: that in the Transylvanian basin also the salt masses pierce the whole series of strata of the Miocene, from the conglomerates at the base to the upper sandstones and marls, and so they, too, cannot be considered as belonging to the Miocene. At Praid, Sovata, and Corond, there are also found in the breccia numerous andesitic fragments (ashes and fragments of rocks) as well as fragments of the aragonitic chemical concretionary deposits of the hot mineral springs that appeared here in connection with the recent volcanic phenomena of Harghita (Fig. 14).

The Tortonian fossils found at Wieliczka and Bochnia in the tectonic breccia of the salt cannot have any stratigraphical importance because the breccia being a tectonic and not a sedimentary formation, in its mass there may be found fossils belonging to all the geological formations that were passed through and brecciated by the salt mass. For instance, in the breccia of the salt domes in the sub-

Carpathians fossils were found which belong to all the geological formations from the Jurassic up to the Upper Pliocene. In the dome of Ocnele Mari (Valcea) there were found in the squeezed synclinal zones of the salt, where the clay breccia had penetrated from the outside, some remains of Oligocene-Miocene plants (carbonized trunks and nuts). In the salt of some of these domes were also found

Fig. 14.—Strata of Aragonite torn from their original position and carried upward in the upper part of the breccia of the Corond salt dome, Transylvania.

pockets of petroleum that came in the same tectonic way from surrounding petroliferous rocks.

Moreover, it is the author's opinion that, not only in the Carpathian region of Rumania, but in any other part of the globe where the salt appears in the form of domes, it is a great mistake if the actual tectonic position of those masses is considered as a stratigraphic one. For, the tectonic breccia surrounding them, the development of which is sometimes enormous, shows obviously that the actual position of the domes is entirely a tectonic and not a stratigraphic one.

This mistake has caused the age of these salt domes to be estimated by most geologists from the age of the oldest strata that remain unbrecciated on the flanks of the anticline in which the salt appears. Thus, in the Carpathian regions the salt domes that appear along the same tectonic lines are considered in Poland as Upper Mediterranean, and in Rumania as Lower Mediterranean, or as Upper Oligocene and Eocene, or even Lower Cretaceous, whereas in Hungary they are considered as Middle Mediterranean.

In the other countries besides the Carpathians the same mistake is made. The Austrians consider the salt of the eastern Alps as Triassic, because the salt masses (Hallstadt) stopped in the Triassic. The Germans, on the same basis, considered theirs as Triassic or Permian, according as they are arrested in the Triassic or the Permian. In Northern Africa the salt masses were considered until lately as Cretaceous, and now, after the discovery of the Triassic in the flanks of the dome, they are considered as Triassic.

In summarizing, the following conclusions, based on scientific observations, are considered as definitely established for the salt domes of the Carpathians.

1. From a regional point of view the Carpathian salt domes are connected almost entirely with the zones of more recent tectonic sinking of Cretaceous and Tertiary time and the sedimentary formations of these depressions. Salt is known only in the form of springs in the zones of intense regional metamorphism (Sinca Noua, Varciorova).

2. The salt masses of the Carpathians came from a considerable depth, emerged only in the anticlinal zones and along the great fault lines, piercing and brecciating all the Mesozoic-Tertiary formations of the geosynclines of the Carpathians, sub-Carpathians, and the Transylvanian basin.

3. Judging from their identical tectonic mode of appearance and from their structure and the composition of their salt, identical in all the salt masses of the Carpathian region, they must all be considered as having a common origin, in whatever formation they may appear today.

4. Judging from the enormous development of the tectonic brec-

cia surrounding them, the actual position of the salt masses presents itself as a tectonic and not at all a stratigraphic problem, and this tectonic position does not furnish any scientific conclusion about the age of the salt. The surrounding geological formations, as well as the fossil remains of the salt breccia, and even of the salt mass, cannot have any stratigraphic value in this case in the determination of its age.

5. Considering that in the Carpathians and in the sub-Carpathians the geological formations that are determined with certainty as penetrated by the salt masses are those between the Middle Cretaceous (Aptian) and the uppermost Pliocene (Levantin), it follows that the salt comes from greater depths than the Aptian of the Carpathian geosyncline. The tectonic breccia of some salt domes (Podenii Noui and Bezdeadu-Bela) contains great, even enormous, *Klippen*, of Jurassic limestone, whose presence in those places cannot be explained otherwise than by the same tectonics which were responsible for the salt breccia in which they are found. Those masses must be considered as coming from a depth greater than the Jurassic of the basement of the Carpathians and sub-Carpathians.

From these considerations, and in the absence of safe stratigraphic data on the age of the salt domes of the Carpathians, it seems more practical to mark, on the geological maps, the salt masses, as well as their tectonic breccia, with special colors and symbols. Although the available data merely prove the salt to be older than the Cretaceous-Paleogene Flysch, the intrusion of the salt cores can be more definitely dated. These intrusions took place at the end of the Pliocene and at the beginning of the Quarternary because the youngest strata that are pierced by all the salt masses of the marginal zone of the southern sub-Carpathians (Baicoi-Tintea, Moreni, Matita, Podenii Noui, etc.) belong to the uppermost Pliocene (Levantin). It is also known that these strong movements gave the last organic modeling to the entire Carpathian region. It cannot be affirmed, however, that the salt masses have made their ascent only during those post-Pliocene movements, and it is possible that their ascent may have been subject to great interruptions, and may have been renewed at successive periods of folding.

HYPOTHESES REGARDING THE AGE AND GENESIS OF THE SALT

What, then, is the age of the salt of the Carpathian salt domes? This problem is of great economic importance for Rumania, because of the close tectonic relations of these salt masses with the formation of petroleum deposits.

In order to discuss this difficult problem, one must leave, at least in part, the sphere of positive scientific data and enter that of hypothesis. On this question the opinion of the author is that the salt masses, not only in the Carpathians, but those of the whole surface of the earth, belong to none of the known marine or continental geological formations (20 and 24). The following arguments lead to this opinion.

A study of the mode of appearance of the salt domes on the whole surface of the earth (27, 28, 29, 30, 31, and others) establishes the following generalized characteristics (it should be remembered that only salt domes are considered, not intercalations of impure salt of unimportant extent and thicknesses that are interstratified in lagunal or epi-continental salt-lake formations:[1]

1. On the whole surface of the earth the salt of salt domes appears in the form of enormous, lenticular masses, with very complicated tectonic structure reflecting the enormous dynamic movements that they have undergone. The salt is crystalline and shows an extraordinary chemical purity.

2. Breccia, in some cases of enormous thickness, surrounds almost all the salt masses, and, being a tectonic formation, shows that the salt mass has penetrated the strata to its present position. This gives a certain basis for considering the salt as coming from greater depths, and doubting all determinations of the age of the salt, based only on the knowledge of the age of the rocks in which the salt mass is found. The case of the Carpathian salt masses and those of Northern Africa is instructive enough on that account.

3. The enormous number of the salt masses, presenting absolutely identical structural and chemical characteristics, appearing in various parts of the world in strata of all geological formations, from

[1] "Some interstratified salt beds are of rather important extension and thickness." —Bloesch.

the Paleozoic to the Quaternary, irrespective of the geological facies of these formations, forces the admission of an absolute independence of the salt masses from all those formations, and consequently their genesis cannot be connected with any of the geological formations in which they appear.

4. Finally, the enormous quantity of pure crystalline salt that is found in thicknesses of hundreds and even thousands of cubic meters in every salt mass; the great number of these masses in the world and in some regions (Carpathians, Germany, Isthmus of Tehuantepec, etc.) grouped in lines so near one another that they almost touch, this widespread occurrence in all the geological formations, independent of the age and the facies, constitute characteristics that, through their generality alone, exclude the admission of any hypothesis that might connect the salt genetically with local geological phenomena as lagoon (32) or desert lakes (33). Besides, the insufficiency of these hypotheses is acknowledged by all who have studied the genesis of salt (5, 34, 35, 36).

All these considerations lead to the admission that the genesis of the salt cannot be connected with anything else than a world-wide phenomenon, the universal character of which might explain those universal characteristics of salt domes. And thus the author was led to connect the genesis of the salt with the hypothesis of saline precipitation on the surface of the first solid crust of the globe, in an atmosphere of a very high temperature (700°–800°) and very rich in vapors of chlorides at this temperature.

Later on, upon condensation the water separated these chlorides, on account of their solubility, and deposited them from these hot solutions in the existing depressions on the surface of the first crust. The temperature of the crust, being still very high, caused frequently re-evaporation of the water. Through re-solution and recrystallization, many times repeated on the surface of this first crust, there were formed numerous sedimentary deposits of salt, chemically pure, and of enormous extent and thickness.

This hypothesis may, perhaps, explain all the peculiar physico-chemical and mineralogical characteristics of the salt, as well as the widespread appearance of the salt domes on the whole surface of the earth, in a manner identical genetically and in most of the known

geological formations. The first ocean that originated through the precipitation of the greatest part of the water of the primitive atmosphere, having dissolved (until saturation) a small part of these saline deposits, covered them with the first marine sediments that were deposited over the salt and protected them from any further destruction. Tectonic movements have caused the salt masses to pierce the entire series of overlying sedimentary formations.

It is the sincere wish of the author that the exact geologic data set forth in this article, with regard to the mode of appearance of the rock-salt masses in the Carpathian region, which cannot longer be considered as Miocene, as well as the hypothesis of the genesis of the rock-salt masses generally, may contribute something to the solution of the important problem of the salt domes.

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DISCUSSION

W. A. J. M. Van Waterschoot van der Gracht: The description of the Rumanian salt domes and the hypothesis of the origin of the domes which Professor Voiteşti has presented are interesting but I cannot at all adhere to his theory. I believe that his explanation is not possible, and also that, if it were possible, it is not necessary to resort to such a hypothesis.

PROFESSOR VOITEŞTI'S THEORY IS NOT POSSIBLE

Professor Voiteşti's original salt deposits of the primary crust should occur in the highly metamorphic and intensely folded rocks, which we encounter everywhere over the globe, below the great major, and practically omnipresent, unconformity, which occurs at the base of the oldest known Azoic and Paleozoic sediments.

Invariably the rocks below this major unconformity, which apparently marks a very decided datum in the evolution of the earth, are very highly metamorphosed; they are principally, if not exclusively, crystalline schists, gneisses, and marbles, with enormous intrusions of old igneous rocks.

This series, of unknown but certainly tremendous thickness, probably does not yet constitute the primary crust, but is nothing else than highly metamorphosed very old sediments and intrusives. This whole series has been universally and intensely folded.

If, as is very possible, salt was ever laid down in these original sediments, it must either have become largely absorbed during the process of intense metamorphism, or, being plastic, must have been squeezed out entirely, before the great pre-Cambrian abrasion and subsequent unconformity. If salt ever was squeezed out as saline plugs by tectonic forces, the event must have been a result of the immense stresses manifested in these archaic rocks.

In consequence, it seems a practical impossibility to me that any rock salt, as such, was left in this archaic series by the time the oldest less metamorphosed sediments were being laid down over this primary unconformity. I am not aware, that, even in the oldest pre-Cambrian and Cambrian beds overlying the unconformity, any salt deposits are known; the oldest saline formations belong to the Silurian,[1] and these are, at least in part, truly sedimentary, and anyway clearly the results of evaporation to dryness of bodies of salt water. The older a salt deposit, the more chance that it has become tectonically displaced, or dissolved by the action of subsurface waters.

Wherever we find salt domes over the world, we know that there is present below them some formation, showing a saline or at least a continental facies. This is the case in Southeastern Europe, notably in the Carpathians. At the end of the Flysch period there occurred in the entire system of geosynclines of southern Eurasia, and among the mountain chains, which are rising up within

[1] Large Cambrian deposits of salt are reported in the salt range of the Punjab, India, but it is possible that these are younger deposits overridden by a thrust fault.—Editor.

them, a breaking up of the original Thetis Ocean into separate basins, and many of these show clear indications that they were subject to intense evaporation. Dr. Voiteşti advances reasons why the salt of the Carpathians did not originate in the Miocene. This is a point for separate discussion in a later paragraph. Here I merely want to emphasize that in Southeastern Europe and the adjacent regions of Asia a saline facies is fairly prevalent, immediately succeeding the Flysch period (Cretaceous-Paleogene).

We do not know the exact origin of the salt in the plugs of the domes surrounding the northwestern shores of the Gulf of Mexico, but here also there exist various possibilities for the presence of formations in a saline facies. Such possibilities exist in the Lower Cretaceous (with red beds and anhydrite) and in the Jurassic (I draw attention here to the occurrence of Jurassic red beds in Mexico in the Huizachal Valley, about 25 km. southwest of Victoria). There is a possibility that saliferous Permian might even be developed in this region, although it is not very probable. It is not absolutely impossible that a Permian basin of this kind should occur over the abraded interior ranges of the Paleozoic mountain system, which evidently underlies these regions, because we have a similar occurrence of this nature in the Gulf of the St. Lawrence (Permian red beds of Prince Edward Island and the Magdalen Islands).

The salt domes in Anatolia, Egypt, and Persia also occur in a region where a saline facies is widely prevalent in the Upper Tertiary, immediately succeeding the Nummulitic. The saline manifestations of the southern Atlas are connected with Triassic red beds, consequently probably with a saline facies.

The salt domes of Northwestern Germany are known to arise out of an enormous blanket deposit of sedimentary rock salt, occurring in several layers, each being hundreds of feet thick, in the Permian and Lower Triassic series, deposited in a great inland basin of red beds, which extends from Poland to the midlands of England.

A similar basin, although salt domes are not known in it (possibly due to the absence of sufficiently strong, lateral tectonic stresses), is known to exist in the western mid-continent of the United States, under the states of Nebraska, Kansas, Oklahoma, and western Texas. Here also several hundreds of feet of clearly sedimentary rock salt is intercalated as a blanket deposit in Permian sediments, evidently the result of the evaporation of a great inland sea.

A similar considerable blanket deposit of rock salt, clearly also a result of evaporation, is known in Alsatia and adjacent regions of Germany. This deposit is of Oligocene age.

It is quite clear, therefore, that in several regions of the globe great blanket deposits of undoubtedly sedimentary rock salt are known, as the result of the evaporation of great bodies of salt water, containing large quantities of sodium chloride, and occasionally, but much more rarely, of salts of other elements; the total bulk of these sedimentary salt deposits is certainly in excess of that present in the saline plugs wherever known. Fairly pure sodium chloride is the result of the main cycle of evaporation; other salts, notably of potassium and

magnesium, are only laid down after the bulk of the sodium chloride has been deposited, and are only found in the depressions, where these final residue solutions have concentrated.

Some of these blanket deposits, notably the Permian salt layers of Northwestern Germany, give birth to saline plugs, because they have been subjected to sufficient lateral tectonic pressure, in addition to the pressure caused by the weight of the overlying formations. This latter weight, apparently, is insufficient, because in other basins, notably that of the mid-continent where a similar weight is present, but sufficiently strong lateral tectonic pressure is not indicated, salt domes apparently have not originated. In consequence, we must assume that in regions where these tectonic stresses have been still much more violent than in the moderately disturbed salt basins of Northwestern Germany, little will have remained of the original sedimentary salt deposit, whether this was a great continuous blanket, like that of Northwestern Germany or of the western mid-continent of the United States, or possibly only isolated salt lenses, the result of the evaporation of minor remnants of an inland sea-arm, or of continental salt lakes.

It is conceivable that in a region subject to such enormous tectonic forces as those which affected the great geosynclines of the Thetis, all along southern Eurasia, nothing at all has remained of original sedimentary salt bodies, which may have been displaced in their entirety, and that whatever salt we find now, is present exclusively as intrusive masses, or, in other words, saline plugs. This may explain why in such intensely compressed regions no sedimentary salt deposits are now found, but it does not mean that they never existed.

If it were true that the intrusive salt masses of the world originated out of the Archaic, we could not explain why salt plugs, although numerous and widely distributed, are nevertheless confined to certain regions of the globe and to certain mountain chains, like the Atlas, the eastern Alps, the Carpathians, and the mountains of Anatolia and Iran; and it would be difficult to explain why, for instance, they are absent in the entire great Cordilleran chain of the Northern and Southern American continents and other mountain systems of the same (generally Tertiary-Cretaceous) age of diastrophism; why also they should be absent over most of the mountain masses of the Permo-Carboniferous and older Paleozoic phases of folding, which occurred at periods when these original archaic salt deposits were less deeply buried and more easily extruded. There are many large mountain systems of these older periods, like the Sudetians underlying part of the Carpathians, in localities which have not been refolded by newer Tertiary diastrophism.

If the salt domes of the North German plain were not of Permian but of Archaic origin, why should they occur only where we know the region to be underlaid by a saliferous Permian, and not, for instance, to the south of the saline facies of the Permian, or within the Permo-Carboniferous Varisco-Armorican chains of Southern and Southwestern Germany, France, Belgium, England, and Ireland?

ARE THE SALT PLUGS OF THE CARPATHIAN REGION OLDER THAN MIOCENE?

So much as to the improbability, if not the impossibility of accepting the Archaic origin of the salt. We will now see whether the observations on the salt domes of the Carpathians make inevitable the assumption that these saline plugs are older than the saline facies of the Tertiary, immediately succeeding the Flysch period.

As Professor Voiteşti states correctly, until lately it has been generally accepted by Carpathian geologists that the salt masses in the Carpathian region as well as those of the eastern Alps, originated from a saline formation in the Miocene, immediately succeeding the Flysch period of this area. Professor Voiteşti contests this on the grounds that the breccia, regularly accompanying the salt plugs, contains numerous rocks belonging to formations older than the Miocene. These older rocks are especially abundant in the breccia of salt plugs occurring in, or very near, the Flysch belt of the Carpathians, but they are also found in other, farther outlying salt domes. Assuming correctly that this breccia results from rocks which the salt plug has pierced on its way to the surface, Professor Voiteşti draws the conclusion that the salt mass, having apparently pierced formations older than Miocene, must be older itself, and must have originated anterior to any of the formations represented in the breccia.

He also points to the fact that, in the Miocene itself, neither blanket nor lenticular masses of salt, which can be considered as sedimentary and in place, are found, but that all the salt in the Miocene has evidently been displaced, and only occupies its present position after considerable relative movement.

As stated previously in this memorandum, there occurs all over Southeastern Europe and adjacent regions in Asia a facies of the regression of the sea immediately succeeding the Cretaceous and older Tertiary Flysch period of the Tertiary mountain systems. Earth movements took place here from early Cretaceous time forward. In the marginal chains, of more recent date than the interior ranges, these movements increased progressively to reach their culmination only in the Pliocene and the early Quaternary.

At the end of the Flysch period, the geosynclinal sea not only regressed, but was divided into several basins by the progressive earth movements; some basins were entirely cut off from the main sea, while others had only very restricted connections. Apparently, climatic conditions contributed toward active evaporation, with the result that all over this region of Eurasia we find evidences of a saline facies during this period. This does not mean that these saline deposits were absolutely contemporaneous in the different localities of this wide region; apparently they are not. Indications of salt occur in different localities from the Oligocene, and possibly the late Eocene, upward well into the Pliocene. It was a general period of salt lagoons and inland salt basins, and apparently in the Carpathian region this facies occurred in the Helvetian Miocene.

The fact that in the Miocene of the Carpathians we do not now find sedimentary masses of salt in place can very easily be explained. As I said before,

the main diastrophism of the present Carpathians occurred after the deposition of the Miocene. In fact, the great overthrust sheets of the Carpathian front all override the Miocene throughout a wide area. This overthrust of gigantic sheets of Lower Tertiary, Cretaceous, and older formations over the Miocene, and subsequent folding all through the late Pliocene and early Quaternary, have subjected this Miocene substratum to enormous stresses. Although locally the Miocene does not seem to be overmuch disturbed along the Carpathian front, it is certain that the pressure to which it must have been subjected was enormous. These overthrust sheets formerly extended much farther than they do now, as their front has regressed considerably on account of erosion. The original front of these thrust sheets also has been pressed and involuted into the Miocene substratum. That this condition is of considerable extent is proved by the Flysch- *Klippen*, which are prominent in many localities, and to which Professor Voiteşti himself refers repeatedly.

Salt is a comparatively plastic mineral, and we know with certitude that whenever a sequence which contains salt beds is subjected to very strong tectonic forces, the salt is displaced and squeezed out as a plastic paste. That such interior movements in shale or clay sequences subject to great tectonic forces may be enormous is demonstrated ever more clearly as we obtain more detailed information regarding the structure and mechanism of great mountain chains. We know, for instance, how the massive limestone reefs, in the shaly Trias of the East Indian arcs, have been acting as stony kernels in a plastic mass, and how these enormous "batoes" have been practically shot through these shales over unbelievable distances by folding. Consequently, we cannot wonder that sedimentary salt lenses, which may have been contained in the Miocene along the front of the Carpathian thrust sheets, or underneath them, have been entirely squeezed out, and are in no place present any more in their original location, but everywhere are found tectonically displaced.

As said before, the Miocene underlies the older thrust sheets of the Carpathians over unknown distances, and has been involuted with older *Klippen* to an unknown extent. Moreover, when this Miocene was deposited, the interior chains of the Carpathians already stood out as large mountain masses, subject to active erosion to the extent, probably, that the interior had already become entirely peneplained. In consequence, material derived from these interior chains and their pre-Carpathian basement must be expected in the Miocene, and is known, in fact, in Miocene conglomerates.

Under these complex conditions, it is only natural that the breccia surrounding the salt plugs should contain fragments of a variety of formations, regardless of the relative ages in an undisturbed sequence, the only requirement being that the intrusive salt and the various formations have come into contact. Many of these salt plugs appear in erosional windows in the thrust sheets, showing Miocene, without it being possible to state definitely whether this latter is the undisturbed autochtonous substratum, or whether these masses of Miocene are either involuted in, or sheared along, under the thrust sheets. A great many

plugs finally pierce the Flysch thrust sheets themselves, apparently rising up from the autochtone underneath them, which, most probably, is Miocene.

I am not familiar with the more recent work in the Carpathians, and I will not go into a detailed discussion of the various individual salt domes. I gather, however, from Dr. Voiteşti's paper, and from other publications, that the pre-Miocene rocks are most conspicuous in the breccia of the salt plugs which occur within the outer front of the Carpathians, or immediately in advance of the front, and that, with the exception of pre-Flysch formations belonging to the Jurassic or the older basement, they are less conspicuous in the outlying domes.

Here I must state again that, in general, we do not know how far the original overthrusted Carpathian front stood in advance of the present front of the Flysch sheets, and neither do we know the conditions at depth in the foreland—notably in the depression between the sub-Carpathians and the Dobrudja.

In conclusion, I still hold to the theory that the salt of the Carpathian plugs is Miocene, for the following reasons: (1) it is the only formation in the entire sequence which we know to contain a saline facies; (2) the saline facies may not contain actual beds of salt *in situ*, but the enormous tectonic forces, to which this sequence has been submitted, easily explains that all the plastic salt must have been tectonically displaced; (3) the presence of pre-Miocene rocks in the breccia, surrounding the salt plugs, can be explained as derived from overlying thrust sheets, which the salt has pierced, or *Klippen*, which it has encountered, or from conglomerates, derived from the older Carpathian chains, occurring within the Miocene; (4) I cannot conceive the origin of the salt to have been in the pre-Miocene sequence of the Carpathian geosyncline, nor in the pre-Carpathian Paleozoic of the underlying Permo-Carboniferous Sudetic-Dobrudjan chains, which give no evidence anywhere of a saline facies in their sequence, or of the occurrence of salt plugs anywhere outside of the Carpathian structure; (5) a still older origin of the salt plugs from the archaic crust seems entirely at variance with what we might expect.

SUBSURFACE GEOLOGY OF WILSON COUNTY, KANSAS

W. L. STRYKER
Fredonia, Kansas

ABSTRACT

The areal geology of Wilson County and the geologic section to the base of the Pennsylvanian are briefly described. The geologic section of the Mississippian and older strata and the surface on the Mississippian are described in detail. The structure of the Pennsylvanian is considered and the hypothesis is advanced that many of the anticlinal and domal structures of the surface Pennsylvanian strata are due to settling over irregularities on the Mississippian surface and lenses of sand in the Pennsylvanian strata. The relation of the deposition of the Pennsylvanian sediments to irregularities on the Mississippian surface is examined and the conclusion is reached that the positions of many of the sand lenses in the Cherokee shales were determined by these irregularities. The structure of the pre-Pennsylvanian strata is considered.

INTRODUCTION

At one time Wilson County ranked high among the counties of Kansas in oil and gas production. It was also one of the earliest producing districts in the Mid-Continent field. Several pools were discovered, but each has gradually declined and many have been abandoned. Of late years Wilson County has received little attention from geologists and oil and gas operators.

The oil and gas of Wilson County were and are derived chiefly from sand bodies in the Cherokee shale, and but few wells were drilled deeper than the base of the Pennsylvanian strata. The discovery of oil below the Pennsylvanian has again stimulated interest in Wilson and other counties of southeastern Kansas.

The writer has endeavored to secure logs of all wells drilled in Wilson County. No logs were kept of many wells and many of those that were kept have been found to have no value. On the basis of the logs considered reliable, sub-surface maps of the various horizons and cross-sections of the strata were prepared. This article presents some of the more important results of the study.

The subsurface map of the top of the Mississippian is considered to be essentially accurate (Plate 23). The cross-sections (Plates 24

and 25) probably contain considerable error, as much interpretation and adjustment of well records was necessary. The structure of the strata beneath the Pennsylvanian is not indicated and opinion is reserved with respect to much of this structure.

In the preparation of this article the writer is indebted to Messrs. M. D. Stryker, B. E. La Dow, C. V. La Dow, and W. H. Twenhofel. Data have been acquired from many drillers, geologists and officials of oil companies.

SURFACE GEOLOGY

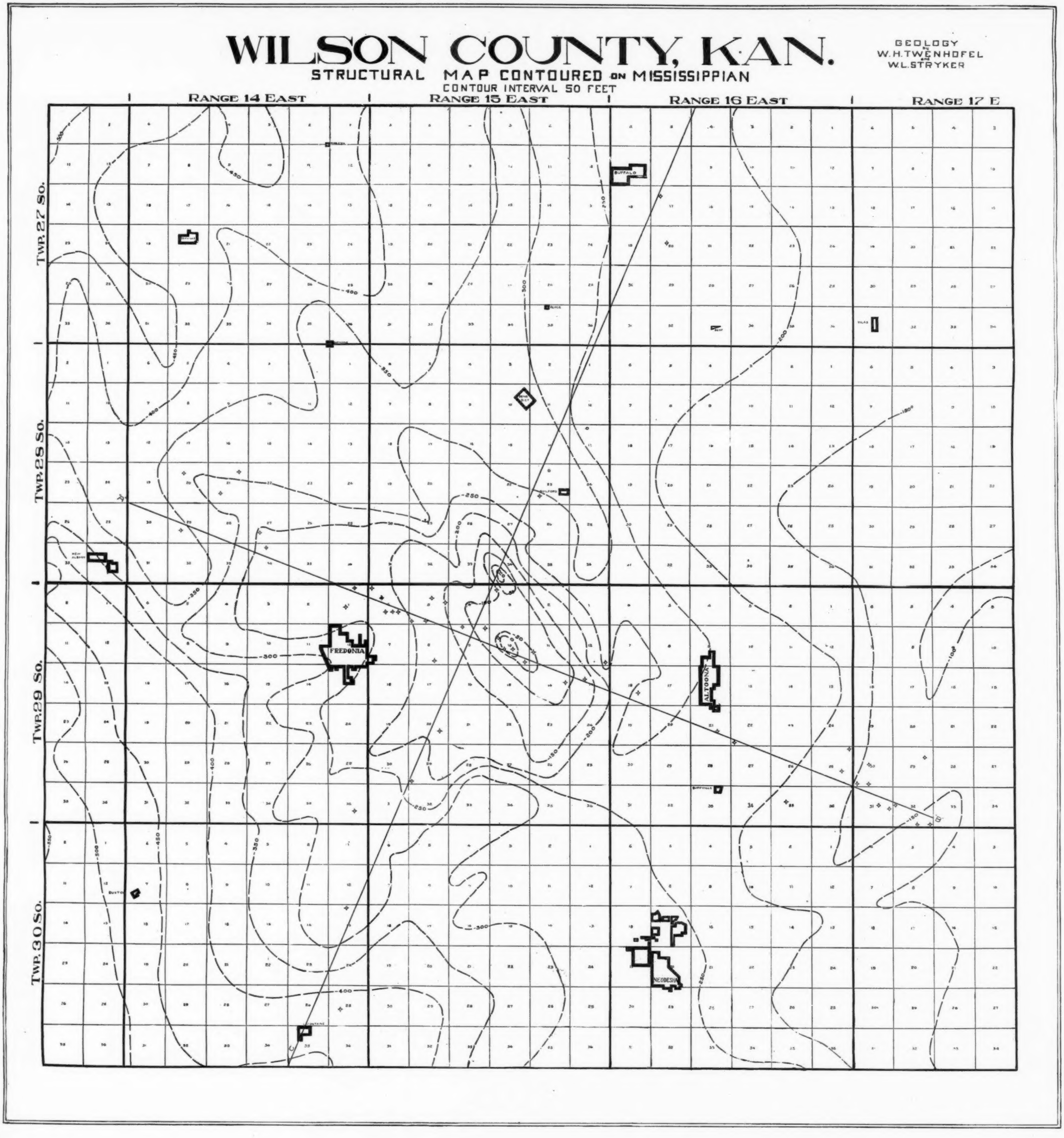
Wilson County is immediately underlain by Pennsylvanian formations which named from east to west are the Kansas City, Lansing, and Douglas.[1] In common with other counties of southeastern Kansas the structure is that of the east limb of the great syncline whose axis crosses central Kansas. The westerly dip approximates 25 feet per mile, but there is considerable range in degree and direction of inclination. In many places the dips are reversed and there are many low domes, anticlines, noses, etc. Some of these have been studied in detail to horizons well down in the Pennsylvanian. Many of them appear to be related to irregularities of deposition and topographic unevenness of the surface of the Mississippian. The most decided structural feature in the surface strata of the county is a dome lying 3 to 4 miles east of Fredonia, the apex being in Sec. 10, T. 29 S., R. 15 E., and is known as the Fredonia anticline, or dome. This anticline has a northwest southeast trend and is 6 or 7 miles long.

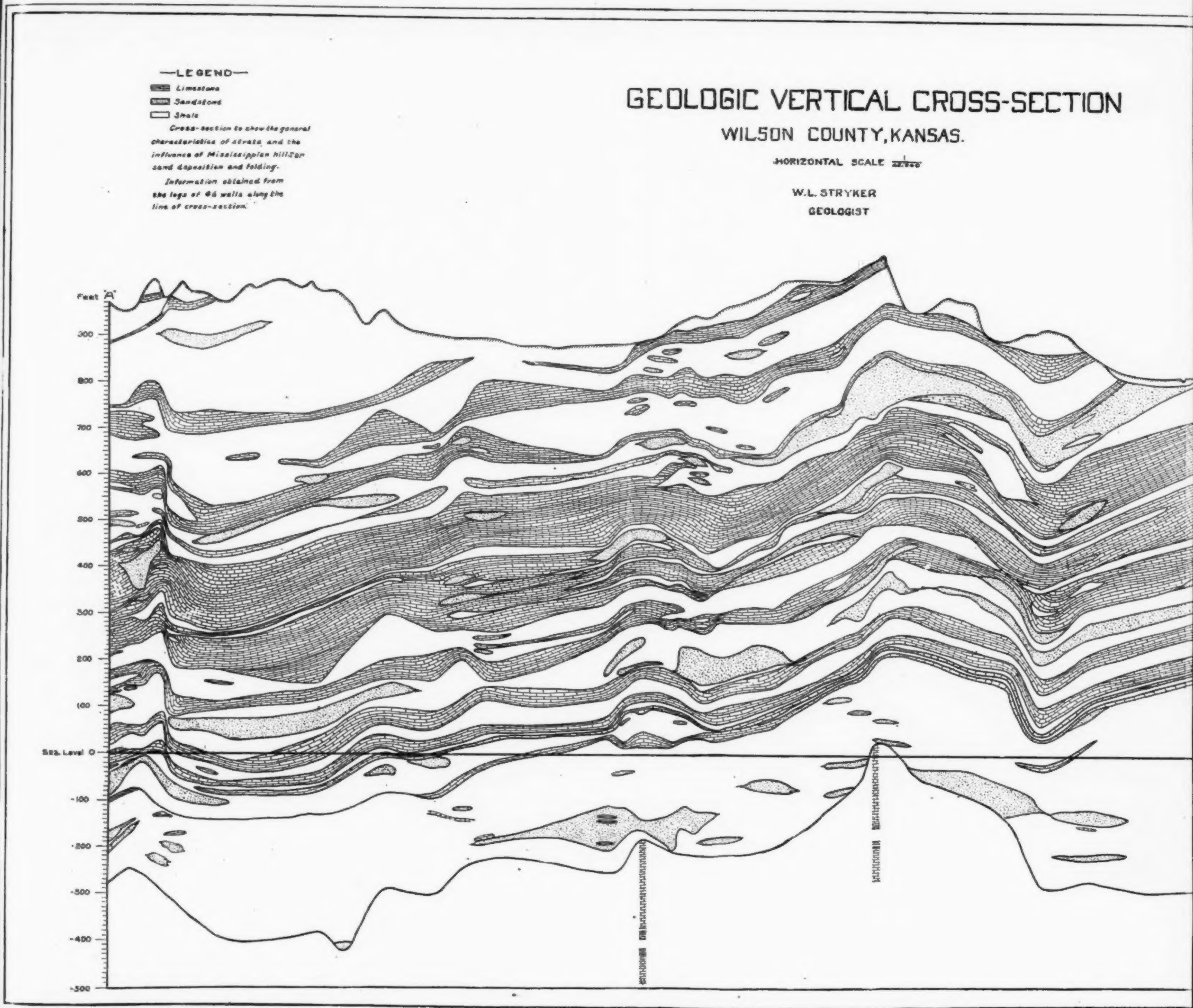
The surface structure of the county has been completely outlined by the writer and others, the Drum, Plattsburg, Stanton, and Iatan limestones being used as key horizons from east to west across the country. The Iatan, particularly the brittle upper bed, is an extremely reliable key horizon. Great caution is essential in using the Stanton to outline structure.

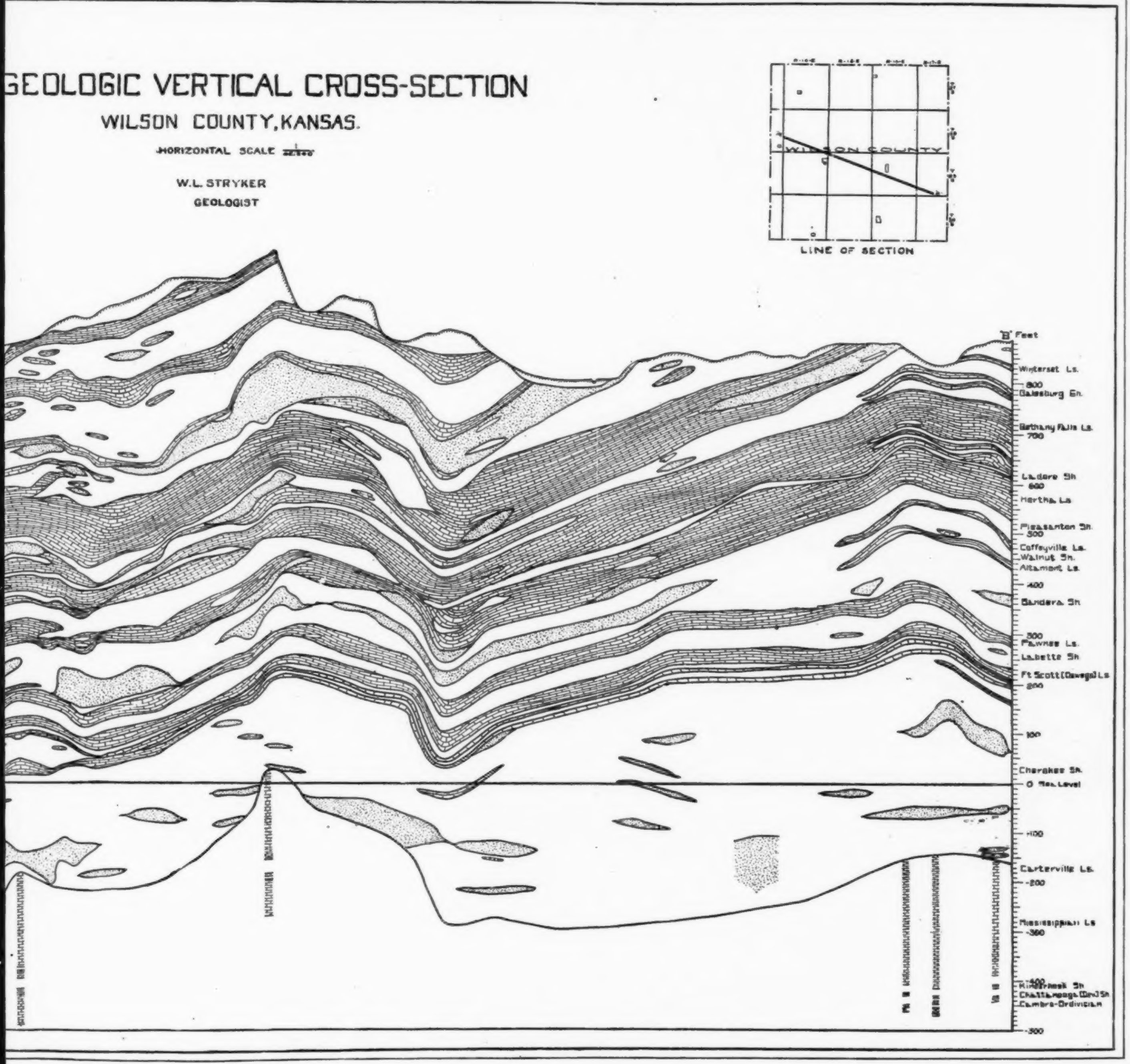
THE CONCEALED STRATA

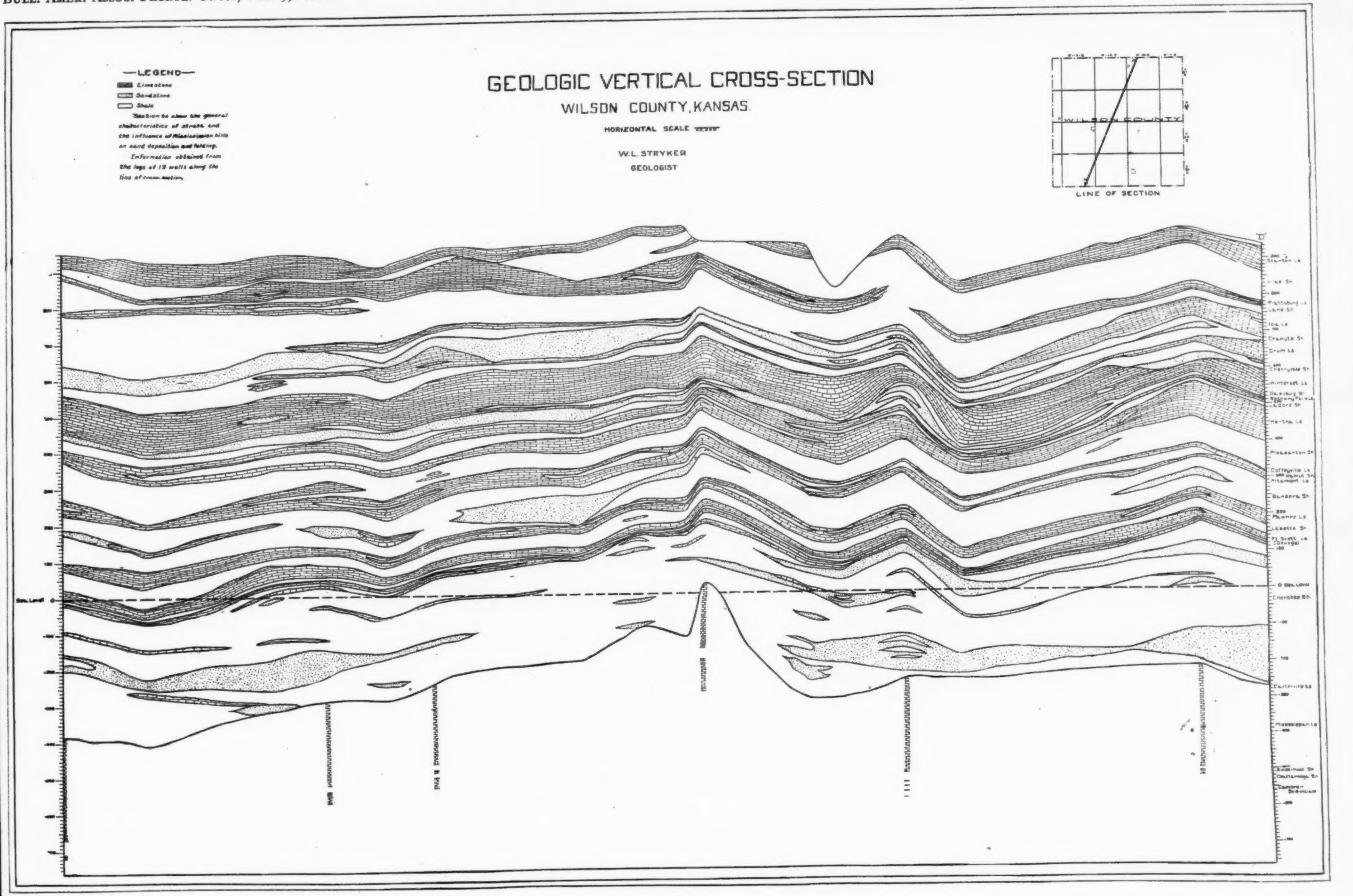
Previously published descriptions of the concealed strata of Wilson County have been based very largely on their appearances

[1] E. Haworth and J. Bennett, *Kansas Geol. Surv.*, Vol. 9 (1908), Pl. XIX; R. C. Moore and C. W. Boughton, "Oil and Gas Resources of Kansas," *Bull. 6, Kansas Geol. Surv.*


WILSON COUNTY, KAN.
STRUCTURAL MAP CONTOURED ON MISSISSIPPIAN
CONTOUR INTERVAL 50 FEET
GEOLOGY BY W. H. TWENHOFEL AND W. L. STRYKER
RANGE 14 EAST
RANGE 15 EAST
RANGE 16 EAST
RANGE 17 E
TWP. 27 SO.
TWP. 28 SO.
TWP. 29 SO.
TWP. 30 SO.
BUFFALO
FREDONIA
ALTOONA
NEODESHA


—LEGEND—
Limestone
Sandstone
Shale
Cross-section to show the general characteristics of strata and the influence of Mississippian hills or sand deposition and folding.
Information obtained from the logs of 46 wells along the line of cross-section.
GEOLOGIC VERTICAL CROSS-SECTION
WILSON COUNTY, KANSAS.
HORIZONTAL SCALE
W.L. STRYKER
GEOLOGIST
Feet
"A"
900
800
700
600
500
400
300
200
100
Sea Level 0
-100
-200
-300
-400
-500


GEOLOGIC VERTICAL CROSS-SECTION
WILSON COUNTY, KANSAS.
HORIZONTAL SCALE
W.L. STRYKER
GEOLOGIST
WILSON COUNTY
LINE OF SECTION
B' Feet
Winterset Ls.
800
Galesburg Sh.
Bethany Falls Ls.
700
Ladore Sh
600
Hertha Ls.
Pleasanton Sh.
Coffeyville Ls.
Walnut Sh.
Altamont Ls.
400
Bandera Sh
300
Pawnee Ls.
Labette Sh
Ft Scott (Oswego) Ls
200
100
Cherokee Sh.
0 Sea Level
-100
Carterville Ls.
-200
Mississippian Ls
-300
-400
Kinderhook Sh
Chattanooga (Dev.) Sh
Cambro-Ordovician


GEOLOGIC VERTICAL CROSS-SECTION
WILSON COUNTY, KANSAS.
HORIZONTAL SCALE
W.L. STRYKER
GEOLOGIST
—LEGEND—
Limestone
Sandstone
Shale
Section to show the general characteristics of strata and the influence of Mississippian hills on sand deposition and folding.
Information obtained from the logs of 19 wells along the line of cross-section.
WILSON COUNTY
LINE OF SECTION
"D"
Stanton Ls
Vilas Sh
Plattsburg Ls
Lane Sh
Iola Ls
Chanute Sh
Drum Ls
Cherryvale Sh
Winterset Ls
Galesburg Sh
Bethany Falls Ls
Ladore Sh
Hertha Ls
Pleasanton Sh
Coffeyville Ls
Walnut Sh
Altamont Ls
Bandera Sh
Pawnee Ls
Labette Sh
Ft. Scott Ls (Oswego)
0 Sea Level
Cherokee Sh.
Mississippian Ls
Chattanooga Sh
Cambro-Ordovician
Sea Level

in outcrops to the east and southeast. Due to the conditions of sedimentation which controlled the deposition of the Pennsylvanian strata there are many variations within short distances. The study of well logs has shown that locally the differences are very decided. Although many members persist from the eastern outcrops into Wilson County, they do not maintain the same thickness; lenses of other rock appear in some of them and others unite or split into two units. These variations are particularly marked in the Cherokee shale, where well logs have shown the presence of sand lenses ranging in thickness up to 180 feet. The position of these sand lenses seems to have been determined in many instances by irregularities on the Mississippian surface and many of them lie on the southwest flank of the irregularities.

It is not considered desirable to name or describe the different formations of the Pennsylvanian in this area as this has been well done by Ley[1] and others.

The Pennsylvanian strata rest unconformably on the Mississippian and many facts indicate that the surface of the unconformity has considerable relief. This relief exercised an influence in the deposition of the sand lenses in the Cherokee shale and may be responsible for some of the structures shown in the surface strata.

From the summit downward the strata beneath the Pennsylvanian are the Carterville, Boone chert, Kinderhook shale, Chattanooga black shale (or a similar black shale), and limestones of Silurian or older age. It is not intended to imply that this sequence is everywhere present beneath the county.

In the Joplin district the Carterville occupies depressions which appear to be sinkholes.[2] The formation is usually very cherty and carries water at the base. It is often productive and is generally known as the top of the Mississippian. Locally the Carterville is absent or thin and it seems to be thickest where the top of the Boone chert is low. This distribution is in harmony with an origin in sinkholes.

[1] H. A. Ley, "Subsurface Observations in Southeastern Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, pp. 445–51.

[2] W. S. T. Smith and C. E. Siebenthal, Joplin Folio, No. 148, *U. S. Geol. Surv.* (1914), p. 5.

The Boone chert lies unconformably beneath the Carterville and is a white to gray crystalline limestone, carrying much chert. In the Joplin district there is a two- to eight-foot oolite member at the top, known as the Short Creek oolite, and about 100 feet below the oolite is a member with a thickness of 15 to 120 feet which is known as the Grand Falls chert. The Boone chert has a thickness in the Joplin district ranging from 140 to 485 feet. On the Rose dome near the south edge of Woodson County, and very near the north edge of Wilson County, the Boone has a thickness of 300 feet. Underlying the Boone chert in this well are 24 feet of light colored shale underlain by 7 feet of sandstone. It is not clear to what system these strata belong. As this well was not drilled below the sandstone it is not known what strata are beneath.

The following data show the distribution and thickness of the Mississippian rocks beneath the county. Under the heading "Mississippi lime," the "top" is the surface of the highest Mississippian formation present and the "bottom" is the bottom of the "Boone" chert.

The "shales" lie below the Boone chert and above the top of the Silurian or older strata. They usually are blue and calcareous and are assigned to the Kinderhook. Below the blue shale is a limestone usually considered as belonging to the Mississippian, and this is underlain by a black, soft, friable bituminous shale which resembles the Chattanooga shale of the Devonian (?). The lower part of this black shale is usually sandy, the sand grains being subangular to rounded.

STRUCTURE OF THE MISSISSIPPIAN AND OLDER STRATA

It does not seem desirable to discuss in detail the structure of the Mississippian and older strata. Beneath the Fredonia dome the top of the Mississippian is about 300 feet higher than it is 3 to 4 miles east, and every known fact justifies the conclusion that a part, if not all, of this high position is a consequence of uplift of the Mississippian subsequent to Pennsylvanian deposition, and that the structure of this dome as shown in the surface strata is a result of crustal deformation and not of settling of Pennsylvanian sediments

over Mississippian hills. The fact that sand lenses seem to have had their distribution determined by the high places on the Mississippian appears to indicate that these were high places before the Pennsylvanian sediments were deposited upon them. Whether they are also structural highs as well as topographic highs is not known, and the writer does not desire to express an opinion.

TABLE I

THICKNESS OF MISSISSIPPIAN ROCKS IN WILSON COUNTY, KANSAS

Name	Location	Mississippi Lime			Shales
		Top	Bottom	Thickness	
Malone	14-30-13	1,573	1,850	277	22
Barb No. 1	33-30-13	1,560	1,820	260	30
Hight	35-30-13	1,586	1,830	244	42
Smith	1-30-14	1,225	1,460	235	29
Fulbright	16-30-15	1,300	1,567	267	36
Edwards	22-30-15	1,310	1,580	270	30
Jones	24-30-15	1,120	1,345	225	60
Blair	27-30-15	1,357	1,602	245	31
Henderson No. 1	10-30-16	1,015	1,268	253	29
Barcus	12-30-16	1,045	1,275	230	25
Neodesha deep well	20-30-16	1,102	1,335	233	30
Bone (Derby)	19-30-17	998	1,212	214	34
Thompson (Halsey)	32-30-17	1,152	1,370	228	32
Arnett	34-30-18	1,015	1,280	265	27
Johnson	13-27-13	1,455	1,721	266	
Brown	2-27-14	1,330	1,609	279	65
Spillman	15-27-14	1,310	1,633	323	27
Steele	29-27-14	1,360	1,576	216	40
Trimmell	29-27-14	1,370	1,590	220	36
Hase	6-27-15	1,332	1,617	285	54
Bushfield	17-27-16	1,188	1,438	250	71
York	23-27-16	1,220	1,472	252	64
Swank	20-27-17	1,110	1,387	277	
Powell	2-28-13				
Morse	13-28-15	1,212	1,475	263	51
Farwell No. 6	34-28-15	935	1,117	182	41
Hoak	31-28-17	1,082	1,321	239	39
O'dell	35-29-14	1,159	1,430		31
Cantrall	36-29-14	1,180	1,405	225	40
Creager	29-29-15	1,177	1,405	228	37
Stewart No. 8	34-29-15	1,315	1,568	253	22
Pendleton	15-29-16	1,035	1,300	265	38
Osborn	29-29-17	1,030	1,280	250	43
Short	30-29-17	1,062	1,315	253	43
Ford	31-29-17	980	1,253	273	35

TABLE II

RECORD OF THE MARIAN SMITH WELL NO. 3, SEC. 10, T. 29 S., R. 15 E., WILSON COUNTY, KANSAS

	Thickness in Feet	Depth in Feet
Soil	3	3
Clay	12	15
White shale	15	30
Sand	10	40
Shale	35	75
Lime	35	110
Shale	5	115
Lime	5	120
Lime and shale	20	140
Shale	30	170
Lime	15	185
Sand gas	125	310
Lime water	100	410
Shale	5	415
Sand show	15	430
Shale	13	443
Lime	25	468
Black shale	8	476
Lime	39	515
Black sand	5	520
Lime	5	525
Black lime	15	540
Black sand and lime	8	548
Shale	7	555
Lime and shale	45	600
Lime	20	620
Shale	35	655
Lime	5	660
Shale	25	685
Sand and shale	30	715
Lime	20	735
Black shale	10	745
White shale	23	768
Lime	26	794
Black shale	6	800
Lime	5	805
Shale	5	810
Lime	5	815
Shale	10	825

TABLE II—*Continued*

	Thickness in Feet	Depth in Feet
Dark shale	35	860
White shale	13	873
Lime	2	875
Dark shale	5	880
S. shale	20	900
Black shale	20	920
White shale	20	940
Dark shale	55	995
Lime gas	56	1,051
Lime	138	1,189
Shale, blue, calcareous	13	1,202
Limestone	7	1,209
Shale, black, calcareous	22	1,231
Limestone, cherty, magnesian, arenaceous	49	1,280
Limestone, cherty, magnesian	45	1,325
Limestone, cherty, magnesian	25	1,350
Limestone, cherty, magnesian	35	1,385
Limestone, cherty, magnesian	26	1,411
Limestone, cherty, magnesian	14	1,425
Limestone, magnesian	15	1,440
Limestone, cherty, magnesian	72	1,512
Limestone, cherty, magnesian	26	1,538
Limestone, cherty, magnesian	14	1,552
Limestone, cherty, magnesian, arenaceous	14	1,566
Limestone, cherty, magnesian	9	1,575
Limestone, cherty, magnesian	15	1,590
Limestone, magnesian, arenaceous	26	1,616
Limestone, cherty, magnesian	31	1,647
Limestone, cherty, magnesian, arenaceous	36	1,683
Limestone, magnesian, arenaceous	31	1,714
Limestone, cherty, magnesian	16	1,730
Limestone, magnesian, arenaceous	47	1,777
Limestone, magnesian, arenaceous	36	1,813
Limestone, magnesian, arenaceous	5	1,818
Limestone, magnesian, arenaceous	12	1,830
Limestone, magnesian, arenaceous	8	1,838
Sandstone, grains rounded to sub-angular	6	1,844
Limestone, magnesian, arenaceous	14	1,858
Limestone, magnesian, cherty	15	1,873
Limestone, magnesian, cherty	43	1,916
Limestone, magnesian, arenaceous	16	1,932
Limestone, magnesian, arenaceous	27	1,959

TABLE II—*Continued*

	Thickness in Feet	Depth in Feet
Limestone, arenaceous	17	1,976
Limestone, magnesian	21	1,997
Limestone, magnesian, cherty	13	2,004
Limestone, magnesian, cherty	6	2,016
Limestone, magnesian, arenaceous	9	2,025
Limestone, magnesian, arenaceous	15	2,040
Limestone, magnesian	10	2,045
Limestone, magnesium carbonate, arenaceous	11	2,061
Sandstone, magnesium carbonate	17	2,078
Sandstone, grains rounded to sub-angular	4	2,082
Sandstone, magnesium carbonate	3	2,085
Limestone, magnesian, arenaceous	33	2,118
Limestone, magnesian	5	2,123
Limestone, magnesian, arenaceous	5	2,128
Limestone, magnesian	22	2,150
Sandstone, magnesium carbonate, grains angular to sub-angular	25	2,175
Sandstone, grains rounded to sub-angular	9	2,184
Sandstone, grains rounded to angular	6	2,190
Sandstone, coarse, grains rounded to sub-angular	6	2,196
Sandstone, coarse, grains sub-angular, some feldspar	15	2,211
Granite	7	2,218
Granite	13	2,231
Granite	13	2,244

CASING RECORD

Inches	Feet
15½	69
12½	560
8	1,538

600 feet east of west line
450 feet north of south line

DISCUSSION

R. A. Conkling: Mr. Stryker says that although there was a 300-foot "high" in the Mississippi lime it was folded after the Pennsylvanian was laid down and that the structure was not due to settling. He then says the sand leases showed that there were irregularities when the Pennsylvanian was deposited. Do not these two statements conflict?

GEOLOGICAL NOTES

AN OUTCROP OF SURFACE OIL SAND IN THE PERMIAN "RED BEDS" OF COKE COUNTY, WEST TEXAS

Surface sandstones, saturated with petroleum, are found at various localities in Coke County, West Texas. The occurrence of these outcrops of oil-bearing sandstones has been noted by Beede,[1] but it is thought that a brief description, accompanied by photograph, of one of the most unique of these outcrops of petroliferous sandstone, will be of interest to geologists.

The junction of North and South Pecan Creeks, Coke County, is about 3 miles southwest of the post-office of Edith. The rocks exposed along the Pecan Creeks are Permian red beds of the Greer stage of the Double Mountain formation—maroon, yellow, and green sandstones, and red, yellow, green, and blue shales, with bands of gypsum. The brilliant coloration and erratic weathering of the high bluffs make attractive scenery.

Fragments of sandstone, soaked with oil, are found in the débris in the bed of South Pecan Creek, and, by tracing these fragments upstream for about a quarter of a mile, one reaches the outcrop of petroleum-saturated sandstone. A bluff about 50 yards long exposes the following section:

	Thickness
Red soil, gravel, and conglomerate	10 ft.
Maroon clay, speckled with blue and carrying thin sands	4 ft.
Massive, soft maroon sandstone	10 ft.
Green and yellow sandy clay	6 in.
Blue-black, heavily oil-saturated sandstone	1–2 ft.
Soft blue and yellow sandstone	3 ft.

This oil-bearing stratum of sandstone is in the fault and structural zone of Coke County, as described by Beede. Concerning the relation of the surface oil sands of Coke County to structure, Beede states: "It (the oil) may have been formed in rocks far below the surface and have reached its present position by rising through faults. So far as has been determined the larger faults in the surface beds and for that matter the more pronounced structures as seen at the surface are in the Pecan Creek region, where oil showings occur. They also occur near Robert E. Lee. In the light of available data, it seems most reason-

[1] J. W. Beede, "Geology of Coke County," *Univ. Texas Bull. 1850*, 1918; "Notes on the Structure and Oil Showings in the Red Beds of Coke County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Norman, Oklahoma, 1919.

able at present to ascribe the origin of the surface oils in Coke County to deep-seated beds."

It has been the general opinion, as suggested in the quotation above, that oil is not indigenous in red bed sediments, because of the extreme rarity of marine fossil remains in such formations. However, the entire question of the occurrence of oil in red beds is an eminently interesting problem, which presents many unsolved aspects. In the Big Lake oil field, Reagan County, Texas, in the same geologic province as Coke County, the major production comes from a depth of approximately 3,000 feet from öolitic, sandy, dolomitic, Permian limestone at the base of the red beds; but at 2,400–2,500 feet a shallow horizon

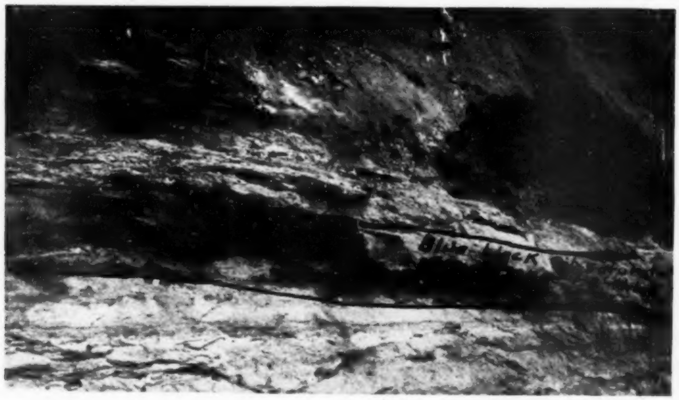


FIG. 1

has been developed which has furnished very large gas wells and a very considerable amount of oil. This shallow horizon occurs in typical Permian red beds which appear to be Double Mountain in age, the same age as the beds in which the surface oil sands of Coke County are found.

It seems to the writer that one of the most fruitful and stimulating subjects of geological research, and one of great practical value to the petroleum industry, in view of the extensive prospecting for new oil fields now under way in West Texas, a region underlain by a thick section of Triassic and Permian red beds—wildcat exploration caused by the discovery and development of the Big Lake oil field, Reagan County, and by the more recent finding in June last of oil in commercial quantities in the Texas Oil World well on the Powell Ranch in upper Crockett County—is the problem of the origin, migration, and concentration of oil as related to its occurrence in association with red beds.

RICHARD A. JONES

SAN ANTONIO, TEXAS

THE ASSOCIATION ROUND TABLE

SUPPLEMENTARY MEMBERSHIP LIST

The following men have been elected to membership or transferred from associate to full membership since the meeting in March. The regular list was printed in Volume 9, No. 2, and a supplementary list in No. 4.

FULL MEMBERS

Artman, George, 515 West Cleveland, Ponca City, Okla.
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Henderson, Junius, 1305 Euclid Ave., Boulder, Colo.
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Sawyer, Roger W., Y.M.C.A., Oklahoma City, Okla.

GEOLOGICAL MEETING IN KANSAS CITY

The annual meeting of the American Association for the Advancement of Science will be held this year in Kansas City, Missouri, with headquarters at the Muehlebach Hotel. Section E (geology) will offer a program of considerable interest to which all geologists in this part of the country and especially petroleum geologists are invited. The meetings will extend from December 28, 1925, to January 2, 1926.

MEETING OF THE PACIFIC SECTION OF THE ASSOCIATION

The annual meeting of the Pacific section of the American Association of Petroleum Geologists was held at the Palace Hotel at San Francisco on Thursday and Friday, November 19 and 20.

The dates set immediately precede the California-Stanford football game, indicating that good entertainment as well as scientific pabulum was not overlooked by the committee on arrangements.

The Executive Committee in charge of the meeting is S. H. Gester, F. S. Hudson, J. B. Case, G. C. Gester, and Roy R. Morse, secretary-treasurer.

A detailed report of the meeting is expected in an early issue of the *Bulletin*.

MEMORIAL

GLENN BECKLEY MORGAN

It is with very sincere regret that we chronicle the death of Glenn Beckley Morgan on September 7, 1925, at Rolla, Missouri. For several years he was an active member of the American Association of Petroleum Geologists, and from 1918 to 1922 he was state geologist of Wyoming.

For nearly three years before his death Mr. Morgan had been in very poor health, and two years ago he underwent an operation at his home in Cheyenne, Wyoming. At times he seemed to improve very greatly, only to grow worse

again, until, a short time before the end, he expressed a desire to return to Rolla, where he had attended college and where relatives lived.

Mr. Morgan was born in Indianapolis, Indiana, October 23, 1876. After completing his public school education he entered the School of Mines at Rolla and graduated from this institution in the class of 1904. Shortly after graduation he accepted the position of mineral and oil expert for the United States Department of the Interior. He has been located at different times at Duluth, Minnesota, San Francisco, California, and later at Cheyenne, Wyoming. In 1918 he resigned his position to become state geologist of Wyoming. In 1922 he resumed his position with the Department of the Interior, and continued in that service until his death.

While at Rolla he joined the Sigma Nu fraternity. In December, 1911, he married Miss Christine Winters of Rolla. He was a man of highest character, and was held in highest esteem by many friends. He held membership in Rolla Lodge of Masons. He was also a member of Wyoming Commandery Knights Templar, and the Consistory, and of the Mystic Order of the Shrine.

Mr. Morgan's published writings relate essentially to the mineral resources of Wyoming.

RAYMOND C. MOORE

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

L. P. TEAS, chief geologist for the Humble Oil and Refining Company at Shreveport, Louisiana, visited in Philadelphia and Atlantic City early in September.

W. W. SCOTT, chief petroleum engineer for the Pure Oil Company at Tulsa, was in Shreveport in September and attended one of the weekly luncheons of the Shreveport Geological Society.

W. E. HOPPER, geologist for the Southwestern Gas and Electric Company of Shreveport, took an extended trip through the fields of southern Texas in August and September.

JULIA GARDNER, of the U. S. Geological Survey, has been mapping areal geology along the Mexican border out of Eagle Pass, Texas, the past summer.

H. W. BELL, supervisor of the minerals division of the Louisiana state conservation department at Shreveport, spent part of his vacation in August and September with his family at Mena, Arkansas.

At a meeting of the Branner Club held in Los Angeles on September 11, PROFESSOR J. J. GALLOWAY, of Columbia University, delivered a most interesting and timely address on "Foraminifera and Their Relation to Oil Geology." A special meeting of this organization was called on September 18 to hear DR. FRANCOIS MATHES, of the U. S. Geological Survey, give his latest views on glaciation in the Yosemite Valley.

The new officers for the Branner Club in Los Angeles are as follows: FRANK S. HUDSON, president; F. P. VICKERY, first vice-president; VAN COURT WARREN, second vice-president; P. L. HENDERSON, secretary-treasurer; and N. L. TALIAFERRO, assistant secretary-treasurer.

E. M. BUTTERWORTH, who has recently returned from a two years' trip abroad for the Standard Oil Company of California, has been placed in charge of geologic work in southern California for this Company, with headquarters in Los Angeles.

JOHN B. KERR, of San Francisco, California, returned the latter part of September from Taft, California, where he made surveys of some oil properties in the Midway and McKittrick oil fields and later studied the oil and gas prospects along the coastal region of northern California.

The Gulf Production Company, L. P. GARRETT, chief geologist, has just proven its third salt dome to be discovered by the seismograph, having drilled

into sulphur-bearing cap rock at a seismograph location near the little town of Fannett, southwest of Beaumont, in Jefferson County, Texas, at a depth of 800 feet.

GILBERT H. CADY, head of the department of geology of the University of Arkansas, Fayetteville, has been appointed senior geologist, in charge of coal studies on the Illinois Geological Survey, to succeed H. E. Culver, who has accepted a position as head of the department of geology at Washington State College, Pullman. Doctor Cady's appointment becomes effective January 1, 1926.

A luncheon was held by the TAMPICO GEOLOGICAL SOCIETY at the Hotel Imperial on September 2. The following were present: W. A. Baker, Chas. D. Vertrees, Lowell J. Ridings, O. A. Larrazola, Jr., J. M. Muir, John Bell, C. Drake, L. B. Kellum, Paul Weaver, Carrol V. Sidwell, James B. Dorr, M. P. White, E. Ordonez, S. S. Roberts, W. M. Small. Geo. L. Rihl, of the Aviation Company, R. A. Smith, of the Fairchild Aerial Survey, T. R. Batte, general manager of the Agwi, and Dr. A. Heim, of the Corona, were present as guests.

DR. HEIM gave a very interesting talk on overthrust faulting in the Galacian fields and in Switzerland. Dr. Heim leaves for The Hague after spending four months on structure studies in the Tampico region.

MR. SMITH, former United States Army man, discussed the methods employed in photographic mapping, and MR. RIHL discussed coasts and advantages of aerial surveys.

RAYMOND R. HAHN, one of our associate members who has been for more than three years in Veterans' Hospital 41, New Haven, New Jersey, has recently removed with Mrs. Hahn to his new bungalow at Barnes, Warren County, Pennsylvania, and hopes to make rapid improvement in the new environment.

ROBERT T. HILL is now doing some special geological work in the vicinity of Los Angeles for the state and county.

FRED H. KAY, who has for some time been in charge of work for the Venezuelan Sun at Caracas, Venezuela, has recently returned to the United States, his present address being The Sun Oil Company, Finance Building, Philadelphia, Pennsylvania.

H. A. BUEHLER, state geologist of Missouri, was recently engaged in geological work in the West. He was on leave for a six-week period.

The annual fall field meeting of the Association of American State Geologists was held October 12–16 in eastern Pennsylvania, the Pennsylvania Geological Survey acting as host. Early arrivals were entertained Sunday evening at the homes of Dr. GEORGE H. ASHLEY and Mr. R. W. STONE. Four days were spent in the vicinity of Harrisburg. Hummelstown, Cornwall, Port Clinton, Pottsville, Mahanoy, Hazelton, Mauch Chunk, Lehigh Gap, Slatedale, North Hampton, and Nazareth in observing the excellent exposures of the stratigraphy and structure, in observing the remarkable peneplain remnants, and in

reviewing the mineral resources of that part of the state, including the southern anthracite field, the slate area, brownstone quarries, cement plants, and the Cornwall magnetite mine. Evenings were devoted to discussions of matters pertaining to State Survey policies and activities and to discussions of the geological problems of the areas covered. The state geologists were accompanied by a number of guests, including Dr. W. C. MENDENHALL, Chief, MESSRS. E. O. ULRICH, CHARLES H. BUTTS, G. W. STOSE, and MISS JONAS, all of the U. S. Geological Survey, Dr. DAVID WHITE, Chairman of the Division of Geology and Geography and Dr. ALBERT L. BARROWS, chairman of the Division of States Relations, National Research Council, Professor W. H. BUCHER, of the University of Cincinnati, PROFESSOR B. L. MILLER, of Lehigh University, JUDGE JAMES R. MACFARLANE, of the Court of Common Pleas, Pittsburgh, and members of the Pennsylvania Geological Survey. The following state geologists represented their respective surveys: GEORGE H. ASHLEY, HERMAN GUNTER, H. B. KUMMEL, M. M. LEIGHTON, RAYMOND C. MOORE, WILBUR A. NELSON, and DAVID REGER (representing I. C. WHITE). The meeting closed at Bethlehem, Pennsylvania, with a dinner at Hotel Bethlehem, at which PRESIDENT RICHARDS of Lehigh University and a number of the faculty were present.

RUSSELL S. KNAPPEN is lecturer in geology at Harvard University this year.

CHARLES W. YEAKEL, associate member of the Association, whose home is in Syracuse, New York, met death through an accident while engaged in work for the Atlantic Refining Company in Venezuela. It is with keen regret that the passing of the soldier on this frontier of civilization's advance is recorded.

J. EARLE BROWN, geologist for the Tidal Oil Company, 2005 W. T. Waggoner Building, Fort Worth, was in Shreveport in September in the interest of his company.

SIDNEY POWERS, of the Amerada Petroleum Corporation, Tulsa, visited Shreveport in September in his capacity as associate editor of this *Bulletin*.

FREDERICK W. GARNJOST, general manager of the Caddo Central Oil and Refining Corporation at Shreveport, has been named a receiver of the Caddo Central Oil and Refining Company of Louisiana, Inc.

The following have been elected officers of the Shreveport Geological Society for the coming year: JOHN S. IVY, president; S. C. STATHERS, vice-president; and L. S. HARLOWE, secretary-treasurer. The society holds regular program meetings on the first Friday night of each month and meets at an informal noonday luncheon every Monday at the Hotel Washington.

S. A. PACKARD, formerly geologist for The Texas Company in Venezuela, South America, is now in the geological department of the same company at Shreveport.

H. W. BELL, supervisor, and M. W. GRIMM, geological engineer of the minerals division of the Louisiana state conservation department at Shreveport were

in charge of an exhibit at the International Petroleum Exposition, Tulsa, Oklahoma, displaying cores and specimens representing the entire geological section in the Shreveport district and samples of all oil produced in that area.

John B. Kerr, consulting geologist, 601 Balboa Building, San Francisco, California, visited friends and former associates in Shreveport in October.

William A. Barth, formerly geologist and valuation engineer with the Imperial Oil and Gas Company, joined the geological department of the Louisiana Oil Refining Corporation at Shreveport in October.

M. E. Wilson, formerly assistant to the vice-president of the Louisiana Oil Refining Corporation at Shreveport, has been appointed manager of the producing department of that organization. His new duties give him supervision of geological, leasing, drilling, and producing activities.

Miss Alva C. Ellisor, in charge of microscopic paleontology for the Humble Oil and Refining Company at Houston, Texas, made a field study of Eocene type localities in Louisiana last October.

G. C. Maddox and W. L. Williams, geologists for the Pure Oil Company of Tulsa, were located in El Dorado, Arkansas, in October, making a subsurface study of the Smackover field.

L. W. Stephenson and C. H. Dane, of the U. S. Geological Survey, and Hugh D. Miser, state geologist of Tennessee, commenced last October a special study of the Upper Cretaceous deposits of southwestern Arkansas that will require several months for completion.

John J. Doyle, of the Humble Oil and Refining Company at Shreveport, won the championship and the mayor's silver cup in the handicap tournament at the municipal golf links last October.

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